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Solar Array Subsystems Study FINAL REPORT

Prepared For
NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

JUNE 6, 1980
CONTRACT NAS3-21926

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Systems Services Company

A DIVISION OF PLANNING RESEARCH CORPORATION

June 6, 1980
ECA-PWR-80-171

NASA-Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135

Attention: Mr. Louis Light, Contracting Officer, MS500-306

Subject: Submission of Final Report

Reference: Contract Number NAS3-21926, Solar Array Subsystem Study

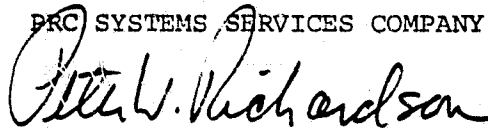
Gentlemen:

In compliance with the referenced contract, the Solar Array Subsystem Study Final Report is hereby submitted.

Should you have any questions, please contact the undersigned at (205) 883-2900.

Very truly yours,

PRC SYSTEMS SERVICES COMPANY



Peter W. Richardson
Project Manager

PWR/bjs

Enclosures: As Stated

Distribution: List as attached

NASA CR-159857

Final Report

SOLAR ARRAY SUBSYSTEMS STUDY

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Prepared For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA-Lewis Research Center

Contract NAS3-21926

FOREWORD

This is the final report of a study entitled Solar Array Subsystems Study performed for NASA Lewis Research Center under Contract NAS3-21926. The technical effort extended from 20 March 1979 through 29 February 1980.

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GLOSSARY

Acronyms

AMO	Air Mass Zero
BOL	Beginning of Life
BSF	Back Surface Field
CCA	Cell Cover Assembly
CDS	Command and Data Subsystem
DDT&E	Design, Development, Test & Evaluation
EOL	End of Life
ESDCS	Energy Storage, Distribution and Conditioning Subsystem
I.C.	Interconnect
LCC	Life Cycle Cost
LCCM	Life Cycle Cost Model
LEO	Low Earth Orbit
mh	Man-hour
MTBF	Mean Time Between Failure
O&M	Operations and Maintenance
OMCS	Operations and Maintenance Crew Subsystem
PCS	Propulsion and Control Subsystem
QA	Quality Assurance
SA&CO	Space Assembly and Checkout
SAPCM	Solar Array Performance & Cost Model
SAS	Solar Array Subsystem
SMS	Structural Mechanical Subsystem
SSPS	Space Services Platform System
TCS	Thermal Control Subsystem
WBS	Work Breakdown Structure

GLOSSARY (Continued)

Greek Symbols

α	Absorptivity
β	Bending moment factor
ϵ	Emissivity
ϕ	Electron Flux (1 mev electrons/cm ²)
η_{BOL}	Cell beginning-of-life efficiency
η_{EOL}	Cell end-of-life efficiency
Γ	Angle of incidence, heat or solar energy
ρ	Density (cubic)
θ	Bending angle (of boom)
ω	Natural frequency

English Symbols

A	Cross section area of boom longeron or area of cell, cover, adhesive, etc.
A_s	Substrate area
B/L	Baseline
C_D	Conductor
C_p	Specific heat
D	Density (of cell, cover, adhesive)
EI	Bending stiffness
f	Boom cross section area factor
F_A	Assembly factor
F_C	Cover factor ($= F_G + F_T$)
F_G	Glassing factor
F_{leak}	High voltage leakage loss factor
F_{p_i}	Cell performance factors
F_{p_j}	Cover performance factors
F_{RAD}	Cell degradation factor

GLOSSARY (Continued)

English Symbols (Continued)

F_{tc}	Temperature cycling factor
F_{TOP}	Temperature derating factor
F_t	Cover degradation factor
I_b	Current
l	Length of boom
M_b	Blanket mass
mCp	Thermal Mass
N_{CH}	Number of channels
P	Tension load
P_{cr}	Critical buckling load
P_D	Power density
P_{mp}	Maximum power cell
Q	Quantity
q_E	Electrical energy
r	effective boom radius
S'	Effective illumination
t	Thickness
\bar{T}	Average temperature
T	Thickness of cell, cover or of substrate, module or panel
Ta_2O_5	Tantalum pentoxide
V_D	Diode voltage drop
V_{IC}	Interconnect voltage drop ($=V_{SC} + V_{mm} + V_{PF} + V_{mb} + V_{sr}$)
V_{mb}	Main bus conductor voltage drop
V_{mm}	Module to module interconnect drop
V_{sr}	Slip ring voltage drop
V_{SC}	Cell connection voltage drop
W	Weight
W_b	Weight of boom
W_{str}	Weight of structure

1.0 INTRODUCTION AND EXECUTIVE SUMMARY

NASA's proposed space programs for the 1980's and 1990's indicate increases in space power requirements in the multi-hundred kilowatt range. Some missions are projected to require as much as 100 to 250 kilowatts of power by the mid to late 1980's. These large space power systems requirements, within this time frame, present a technical and economic challenge to NASA. The projected costs of multi-hundred kilowatt systems based on present technology cost is considerable and becomes a constraint on a number and types of space programs NASA will be able to carry out.

Historically the solar array subsystem's costs have contributed a significant percent of total space power systems costs. This makes the solar array a logical candidate for potential cost reduction of the total space power systems. One of the most effective approaches to cost reduction in the past has been through technology advances, yet the relationships between total systems cost and the many solar array technologies have not been established.

While there is considerable commonality in the different mission requirements placed on the photovoltaic space power system there are also many unique requirements for each class of missions. This suggests that it would be productive to examine each class of missions separately. The class of missions which has the potential for providing considerable cost reduction through technology is the high-power low-earth-orbit Space Platform. This is one of several large earth orbiting satellites proposed which can yet be impacted through advanced technology. This is the type of baseline mission which is to be analyzed in this study.

1.1 Objective and Purpose of Study

It is the purpose of this study to establish the cost-technology relationships of a 500 kW (250 kW continuous to load) silicon planar solar array subsystem for a low-earth-orbit Space Platform type of mission. The study is to identify areas of new technology which if the technology were incorporated, would reduce the cost of space power systems in the LEO, large space platform mission class.

Stated another way, the study is to establish the relative sensitivity of array life cycle costs (LCC) to variation in parameters such as cell thickness, blanket temperature, and cell/cover degradation. The cost of implementing specific technology solutions is, however, not quantified. For example, the effect of blanket temperature on life cycle costs was determined to be \$3.2 million per degree centigrade (in the vicinity of the baseline), however, the impact on array parameters and hence the cost of the means to achieve a particular blanket temperature was not quantified.

However, the capability exists within the model to determine these relationships, given the specific technology.

1.2 Approach to the Study

From the outset, the technique and model to be applied to the study objectives was developed with adaptability and versatility as key features. This would enable application of the solar array model to a large spectrum of mission classes and at the same time provide quantification of life cycle (LCC) costs versus technologies for the specific mission class of this study. Further, the technique was developed to accommodate any analog relationship; for example, solar cell thickness versus cell efficiency or cell/cover degradation characteristics versus end-of-life array power output. The model, while used to quantify the influence of varied technology parameters versus LCC for a baseline design, can be used to optimize the baseline, and with modification, a broad spectrum of missions.

The study was performed in four phases, or tasks:

- Task I - Determination of characteristics of a 500 kW Solar Array Subsystem (a baseline design)
- Task II - Determination of Total Cost (LCC) for the Baseline Subsystem
- Task III - Analysis of Cost-Technology Parameters (LCC vs. Technology)
- Task IV - Reporting

The sequencing of these tasks is shown in Exhibit 1-1.

The approach and general results obtained within each task are summarized in the following paragraphs. Detailed discussion of results is provided in Sections 2.0 through 7.0 for each task/subtask, as specifically referenced in this section.

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NAS3-21926

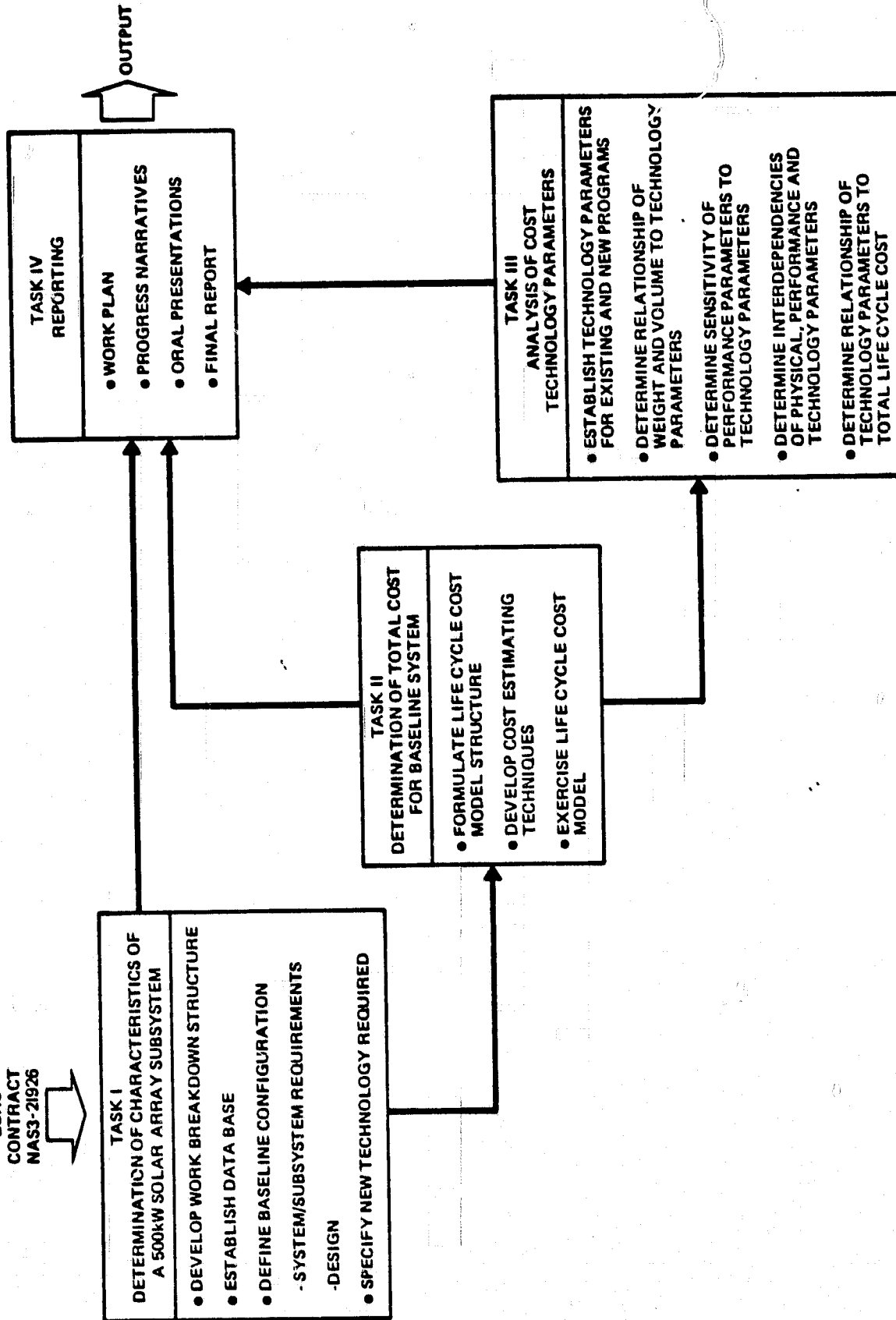


EXHIBIT 1-1. SOLAR ARRAY SUBSYSTEM STUDY

1.2.1 Task I - Determination of Characteristics of a 500 kW Solar Array Subsystem

The purpose/objective of this task was to develop a conceptual baseline solar array subsystem design. The design was developed to a level of detail considered necessary to support a variation of technology parameter values, for example, cell/cover assembly life degradation, bus voltage level, life/reliability and others. Further, the design included scenarios for manufacturing processes, space transportation, assembly and checkout, and operations and maintenance, again parametrically variable to support cost/technology analyses.

Ground rules for the design called for a silicon planar array, use of existing and proven technology, Shuttle transportation, and an operational date in the 1985-1995 time frame.

Task I consisted of four subtasks:

- Subtask I-1: Develop the Work Breakdown Structure (WBS)
- Subtask I-2: Establish the Data Base
- Subtask I-3: Define the Solar Array Baseline Configuration
- Subtask I-4: Specify (any) New Technology Required

1.2.1.1 Subtask I-1: Develop the Work Breakdown Structure (WBS)

The WBS was developed initially to accommodate any configuration and then made more specific to reflect the baseline array subsystem configuration. The resulting WBS is shown in Exhibit 1-2. The WBS served as the basis for the life cycle cost model (LCCM) developed in Task II, (Section 4.0) and for the manufacturing, space assembly and check-out, and operations and maintenance functional flows, (Section 3.0). The WBS is discussed in more detail in Section 2.3.

1.2.1.2 Subtask I-2: Establish the Data Base

A base was established to provide technical, cost and programmatic data for this study. The data base was researched and summary data sheets developed on approximately 50 historical and planned space solar arrays to provide fast access to technical and cost information as required.

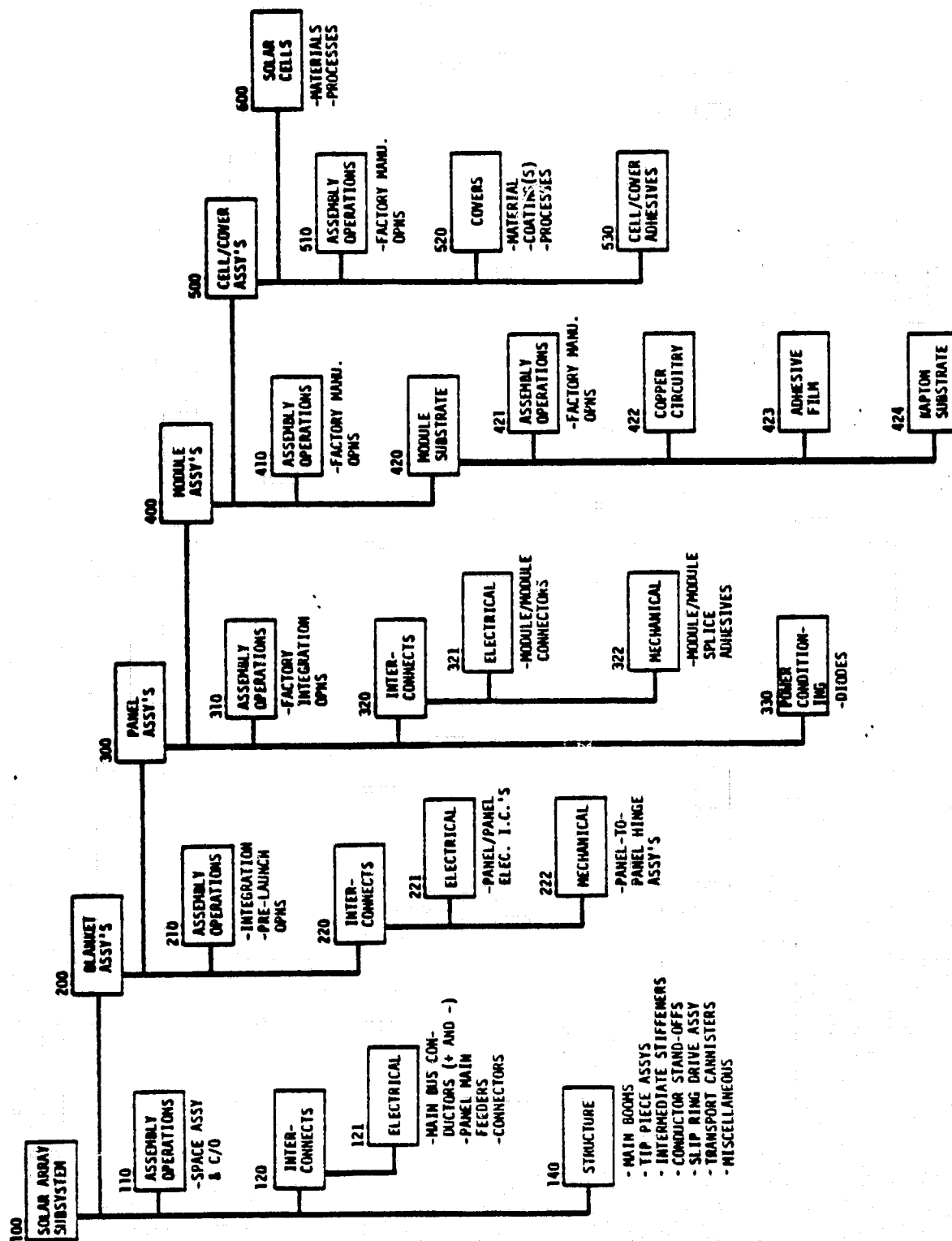


EXHIBIT 1-2. SAS WORK BREAKDOWN STRUCTURE

1.2.1.3 Subtask I-3: Define the Solar Array Baseline Configuration

The definition of a baseline array configuration was preceded by development of system/subsystem requirements. These requirements were developed for the study and documented in a "Specification of Requirements, 500 kW Solar Array Subsystem," which is provided as Appendix A. The specification is summarized in the following paragraphs.

A Space Services Platform System (SSPS) was conceptualized to create a system structure within which a Solar Array Subsystem (SAS) could be defined to provide a baseline design for the study. The purpose of the Space Services Platform System (SSPS) is to provide services to varied User Systems. The User Systems may be engaged in materials processing, manufacturing, astronomy, solar system and earth observation, life sciences, communications, testing and other operations. The User Systems may be secured to the platform or docked for servicing or short-term operations. The general configuration of the SSPS is shown in Exhibit 1-3. The subsystems of the SSPS, their functions and major interfaces are summarized in Exhibit 1-4.

The major system requirements on the SSPS, and the subsystem requirements on the SAS, are:

- System operational 1985-1995
- State-of-art (1979) design
- Silicon solar cells; planar array (no concentration)
- Transportation to LEO: Shuttle
- LEO Orbit: 444 km. Inclination 55°
- 250 kW continuous to loads, provided in 48 individual power channels to the ESDCS subsystem at the slip ring interface
- Provide this output from BOL to EOL
- Varied angle to sun to maintain 250 kW to load
- Bus voltage for users to be:
 - 30 VDC = small, experimental projects (20% of power)
 - 100-250 VDC-intermediate power projects and other SSPS subsystems (30% of power)
 - 1000 VDC-manufacturing, processing, large ion engine testing (50% of power)
- 10 Year Life before SAS solar blanket replacement
- Folded blankets for space transport

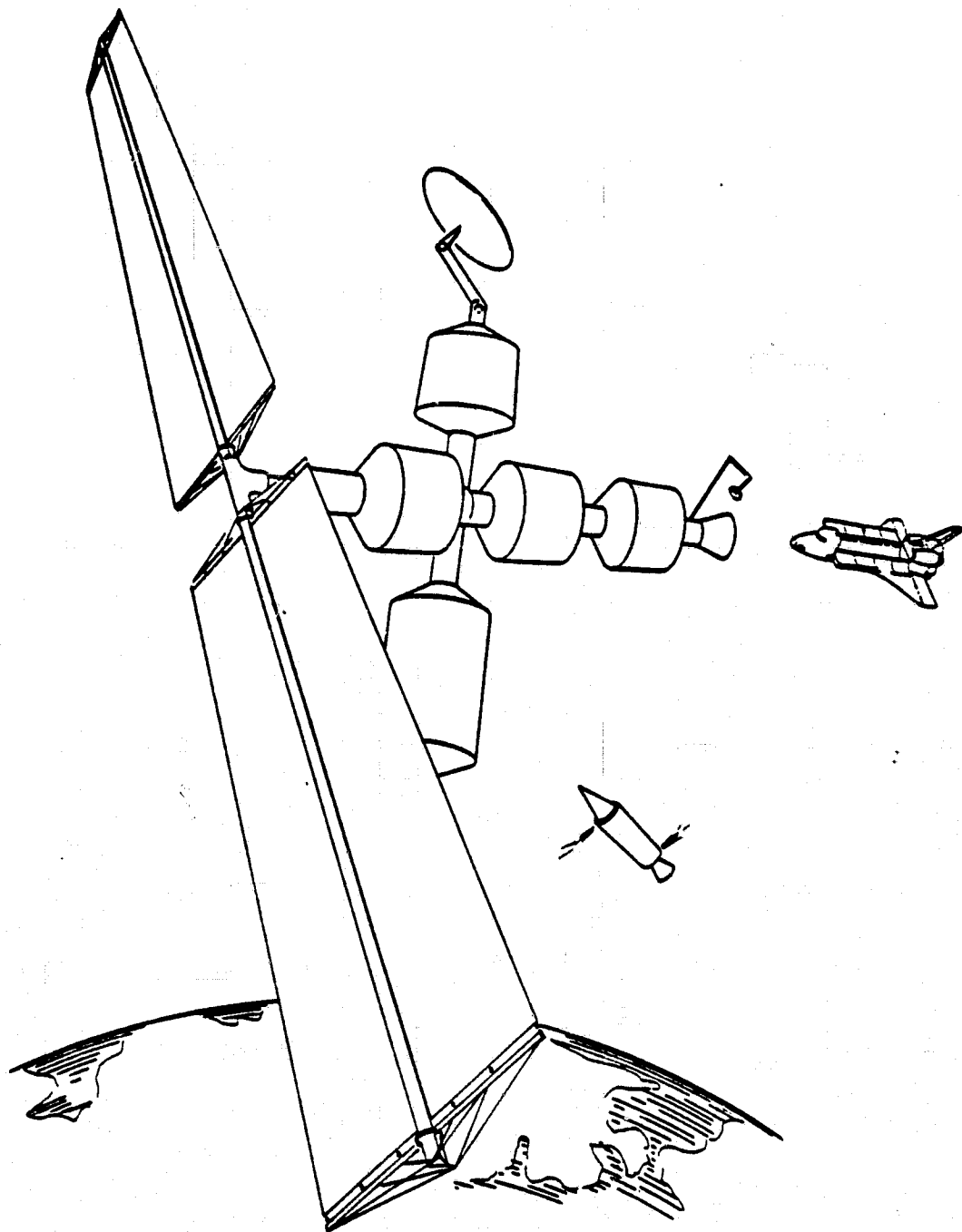
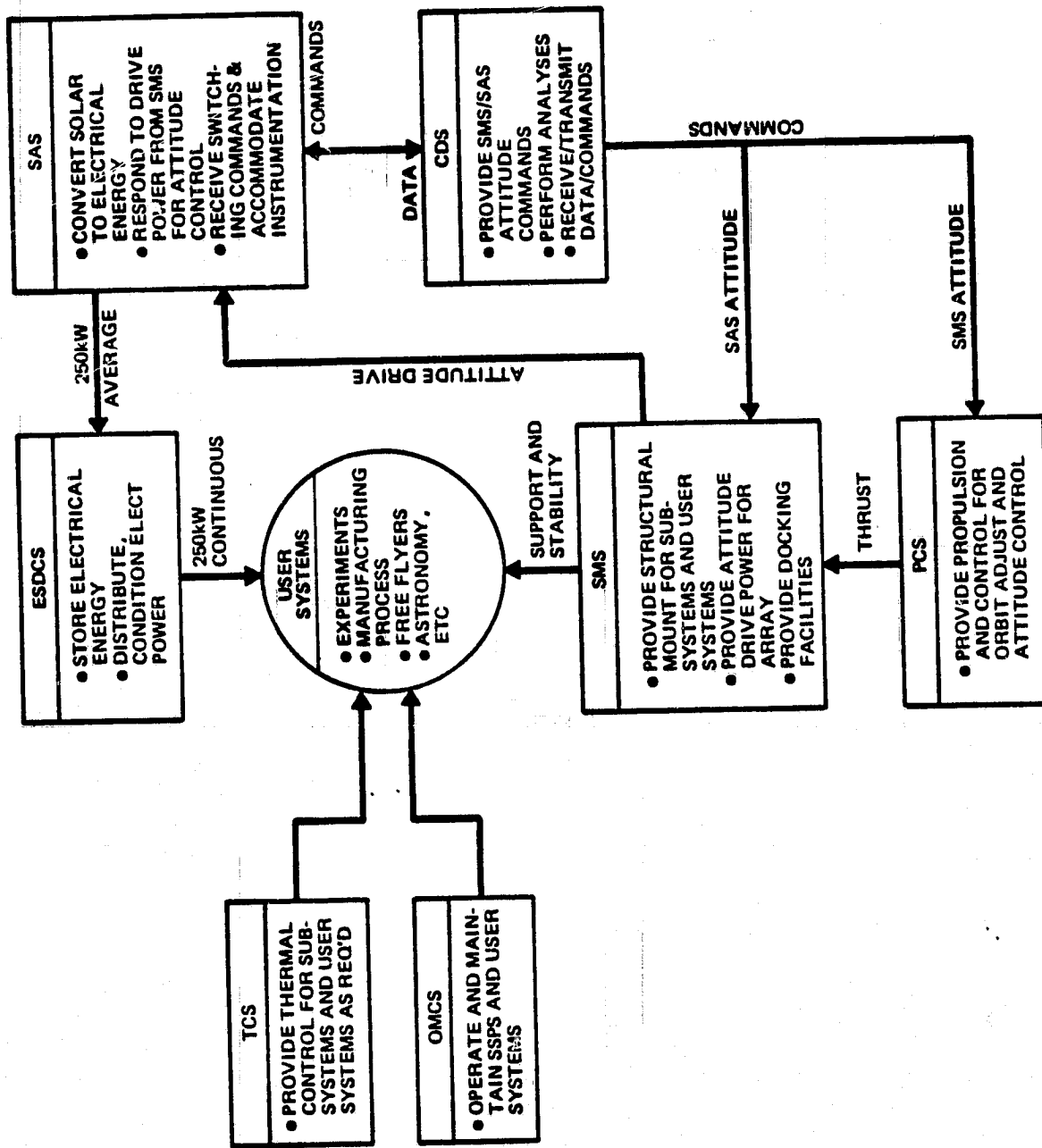


EXHIBIT 1-3. SPACE SERVICES PLATFORM SYSTEM



LEGEND:

- SAS SOLAR ARRAY SUBSYSTEMS
- CDS COMMAND AND DATA SUBSYSTEM
- SMS STRUCTURAL MECHANICAL SUBSYSTEM
- PCS PROPULSION AND CONTROL SUBSYSTEM
- OMCS OPERATIONS AND MAINTENANCE CREW SUBSYSTEM
- TCS THERMAL CONTROL SUBSYSTEM
- ESDCS ELECTRICAL STORAGE, DISTRIBUTION AND CONDITIONING SUBSYSTEM

EXHIBIT 1-4. SSPS SUBSYSTEM INTERFACES AND FUNCTIONS

- Astronaut assembly and check-out, assisted by maneuverable work platforms
- Panel level replacement by astronauts for maintenance (when power output degrades below design value)

The derived requirements on the SAS are:

- Orbit Parameters
 - period 87.3 minutes
 - illumination 53.7 minutes
 - eclipse 33.6 minutes
 - # cycles 60,239 in ten years
- Array Electrical Requirements:

	<u>ENERGY</u>	<u>POWER</u>
Total Per Orbit - Array	429.60 kW HR	480 kW
- To User	223.75 kW HR	250 kW
- To Energy Storage Subsystem (68%)	205.85 kW HR	230 kW

The conceptual design of the baseline SAS was developed to a level of detail required to support the cost/technology analyses of Task III. The design approach, generally, was to

- select the baseline cell, cover, substrate and circuitry
- determine the value of the factors which affect performance and apply to the baseline cell/cover assembly to determine EOL performance. This can be expressed as,

$$EOL P_{mp} (W/m^2) = [(\eta_{BOL} \times \prod_{i=1}^{11} F_{p_i}) \times (S' \times \prod_{j=1}^2 F_{p_j}) \times PF] \times A_s$$

Where P_{mp} = cell max power

F_{p_i} = Cell performance factors

F_{p_j} = Cover performance factors

S' = effective illumination

η_{BOL} = cell BOL efficiency

PF = per-cell packing factor

A_s = per-cell array area

- determine number of cell/cover assemblies required for baseline orbit and load power/energy requirements
- determine total array area, dimensions and structural (a function of mass and dimensions) requirements
- determine array weight breakdown and totals.

The resulting baseline array conceptual design, covered in detail in Section 2.0, is summarized as follows:

The baseline SAS is a two-wing planar array, with dimensions as shown in Exhibit 1-5. A single boom structure (one for each wing) will hold the array blankets in tension using tip pieces as shown. On each wing at eleven equidistant positions along the length of each blanket will be intermediate stiffeners to aid in maintaining planarity. These extend across the boom through spreader rings. The hierarchy of the array is shown in Exhibit 1-6.

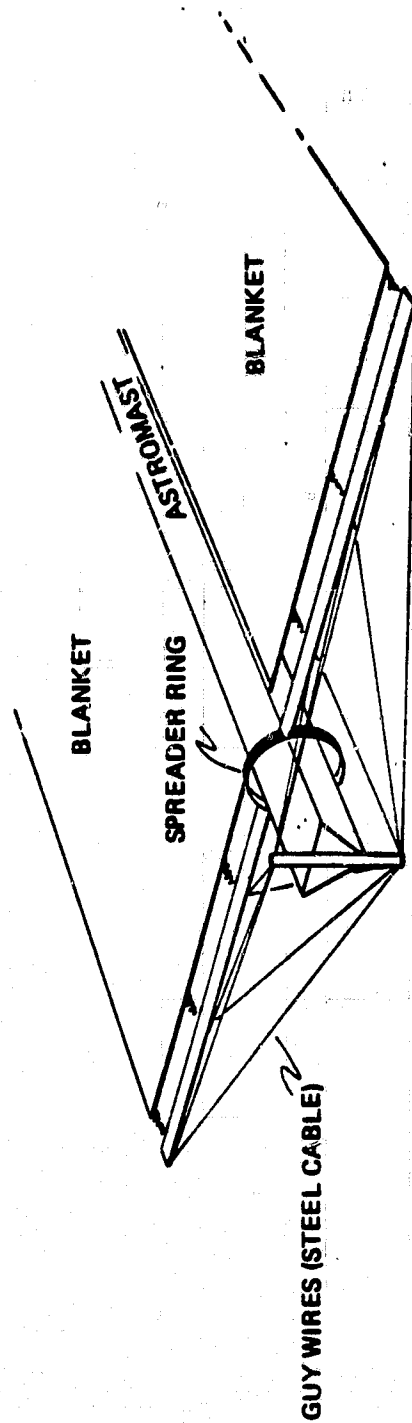
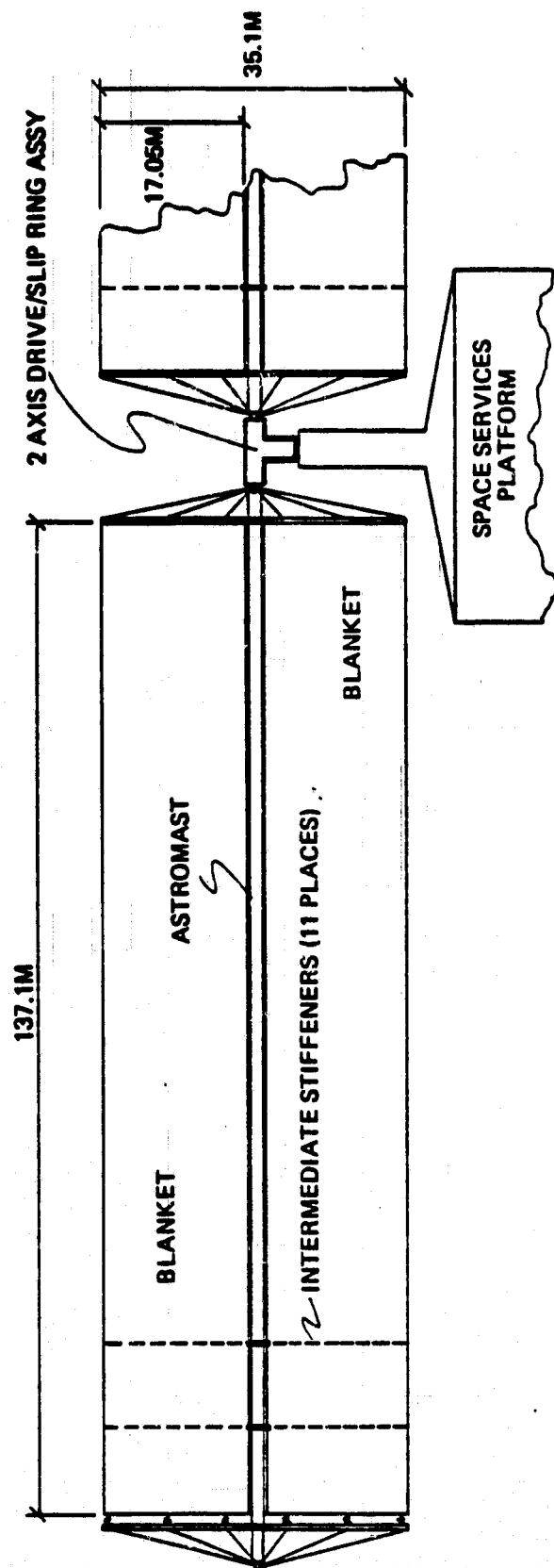
The electrical power will be bussed to the centrally located slip-ring assembly. The bus conductors will be supported by semi-circular (300°) light weight insulator segments attached to the booms. The slip ring assembly is double-gimballed to make independent the orientations and motions of the array and the SSPS platform. The EOL array output will be held constant over the array life by varying the sun-vector/array plane intersection angle.

The power generated by the array is provided at 198 VDC by 48 independent channels at the slip ring output. Each channel provides 10 kW of power. This power level is on the same order of magnitude as the Spacelab and Shuttle.

The use of 48 independent power circuits in the design, while requiring multiple slip rings, is considered compatible with a multi-user operation. Also, this configuration is closer to the space state-of-the-art for slip rings. The use of one or a few high power regulators versus the 48 relatively low power regulators suggested in this baseline design is subject to trade analyses.

The weight statement for the SAS baseline design concept is contained in Exhibit 1-7.

Definition of the baseline subsystem included the flow sequencing, timelining, manloading (numbers, manhours and skills) and the facilities and equipments required to perform DDT&E, Production, and Operations and Maintenance. This is covered in detail in Section 3.0. In summary, the SAS subsystem and system requirements (Appendix A) which drive the flows and the facility, equipment,



TIP DETAIL

EXHIBIT 1-5. BASELINE SOLAR ARRAY LAYOUT

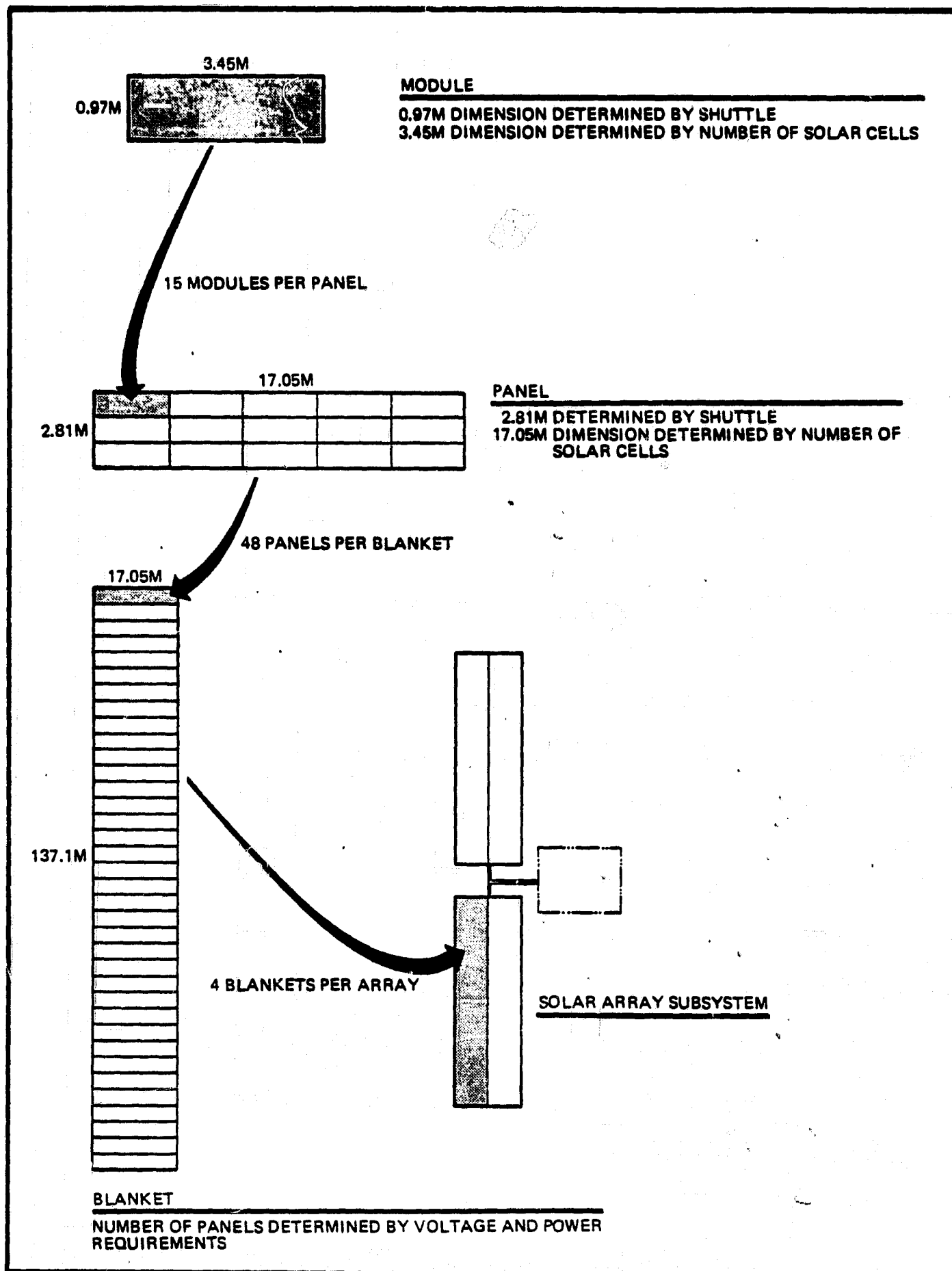


EXHIBIT 1-6. SAS HIERARCHY

WEIGHT (KG)

ELEMENT

PANEL LEVEL

MODULES (15/PANEL) 42.48

ELECT. INTERCONNECTS 0.75

TOTAL EACH PANEL 43.23

BLANKET LEVEL

PANELS (48/BLANKET) 2075

MECHANICAL INTERCONNECTS 751

COMPRESSION PLATE CUSHIONS 128

ELECT. INTERCONNECTS 31

TOTAL EACH BLANKET 2985

ARRAY LEVEL

BLANKETS (4/ARRAY) 11,940

STRUCTURE (INCL. SLIP-RINGS) 7778

MAIN BUS CONDUCTORS 656

TOTAL FOR ARRAY 20,374

EXHIBIT 1-7. BASELINE WEIGHT STATEMENT

manloading, scheduling, and transportation requirements are:

- System Operational 1985-1995
- State-of-art
- Transport by Shuttle
- Space assembly of SAS by equipment assisted crews
- Overhaul at 10 years
- Panel replacement at 90% Po (EOL)
- Spares availability in space
- On-station O&M crew
- Panel level replacement capability
- 24 man-hour panel replacement time
- Automated fault isolation

The top level DDT&E, Production and O&M functional flows are shown in Exhibits 1-8, 1-9, and 1-10 respectively.

1.2.2 Task II - Determination of Total Cost for Baseline Subsystem

The purpose/objective of this task was to develop a life cycle cost model (LCCM) for use in the Task III technology vs. cost analyses, and to determine the life cycle cost (LCC) of the baseline array (SAS).

Task II consisted of three subtasks:

- Subtask II-1: Formulate the LCCM Structure
- Subtask II-2: Develop Cost Estimating Techniques
- Subtask II-3: Exercise the LCCM

1.2.2.1 Subtask II-1 - Formulate the LCCM Structure

The LCCM structure was derived from the WBS (Exhibit 1-2) and the flow diagrams for the Production and O&M flow diagrams (Exhibits 1-8, 1-9). The top level LCCM structure is shown in Exhibit 1-11. The LCCM is discussed in detail in Section 4.0.

1.2.2.2 Subtask II-2 - Develop Cost Estimating Techniques

The purpose of this subtask was to develop the cost estimating relationships to be used to obtain cost estimates for each element of the LCCM. The sources and the relationships used are discussed in detail in Section 4.0.

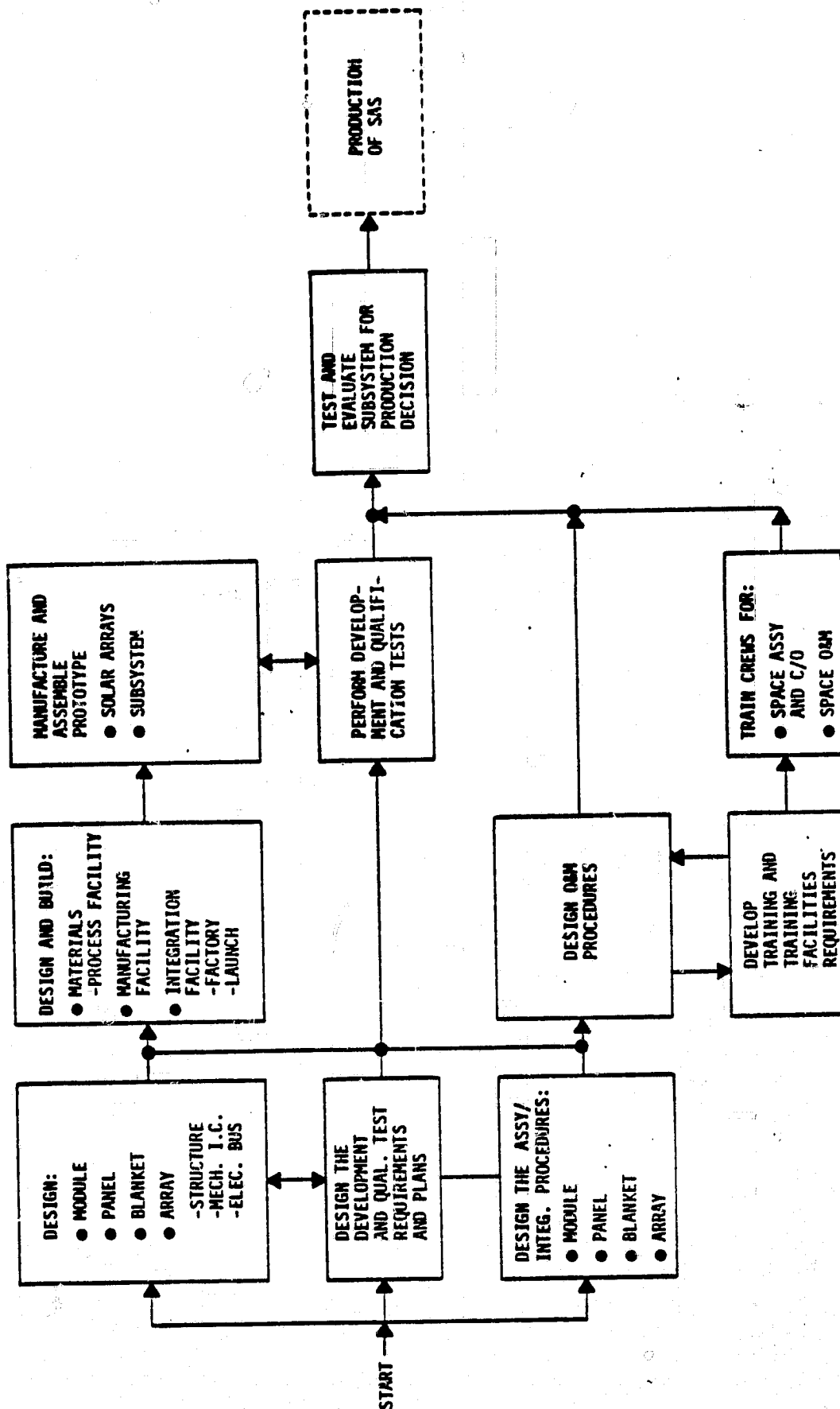


EXHIBIT 1-8. DDT&E FUNCTIONAL FLOW

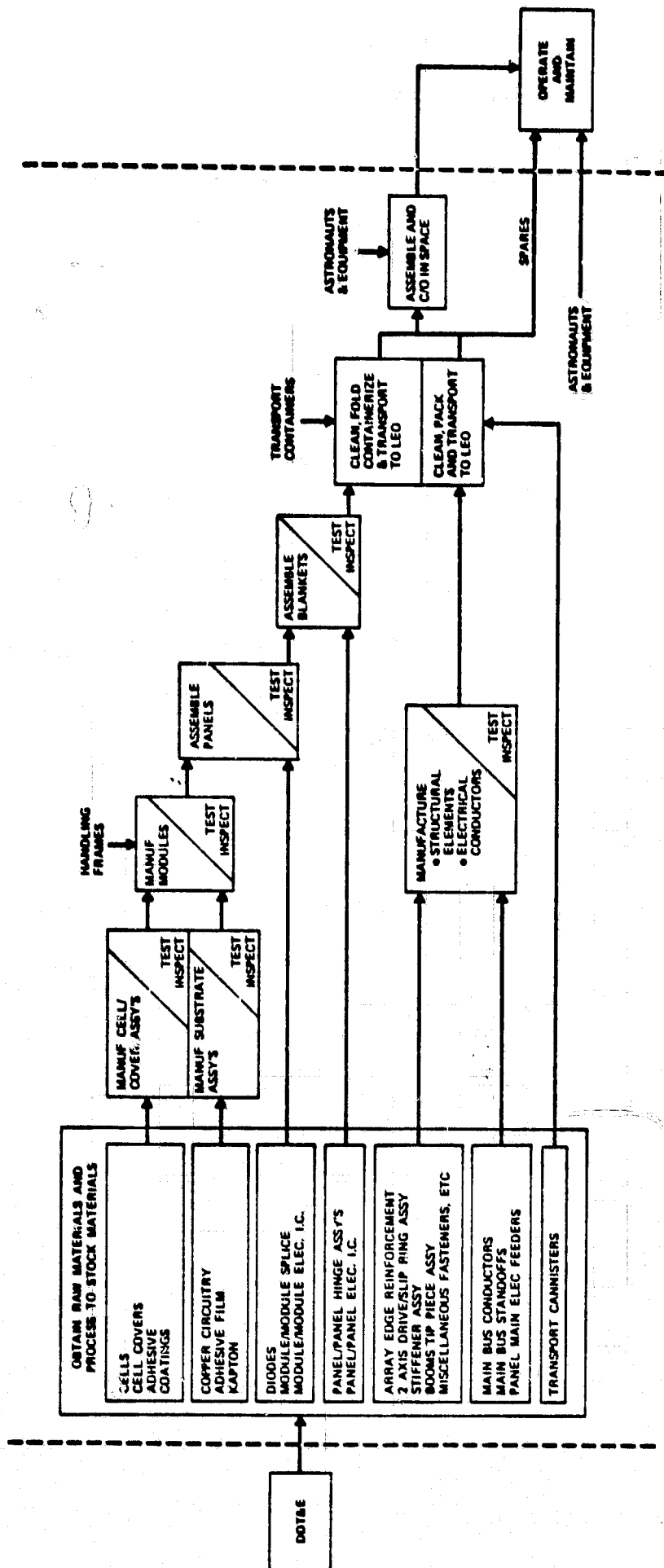


EXHIBIT 1-9. PRODUCTION FUNCTIONAL FLOW

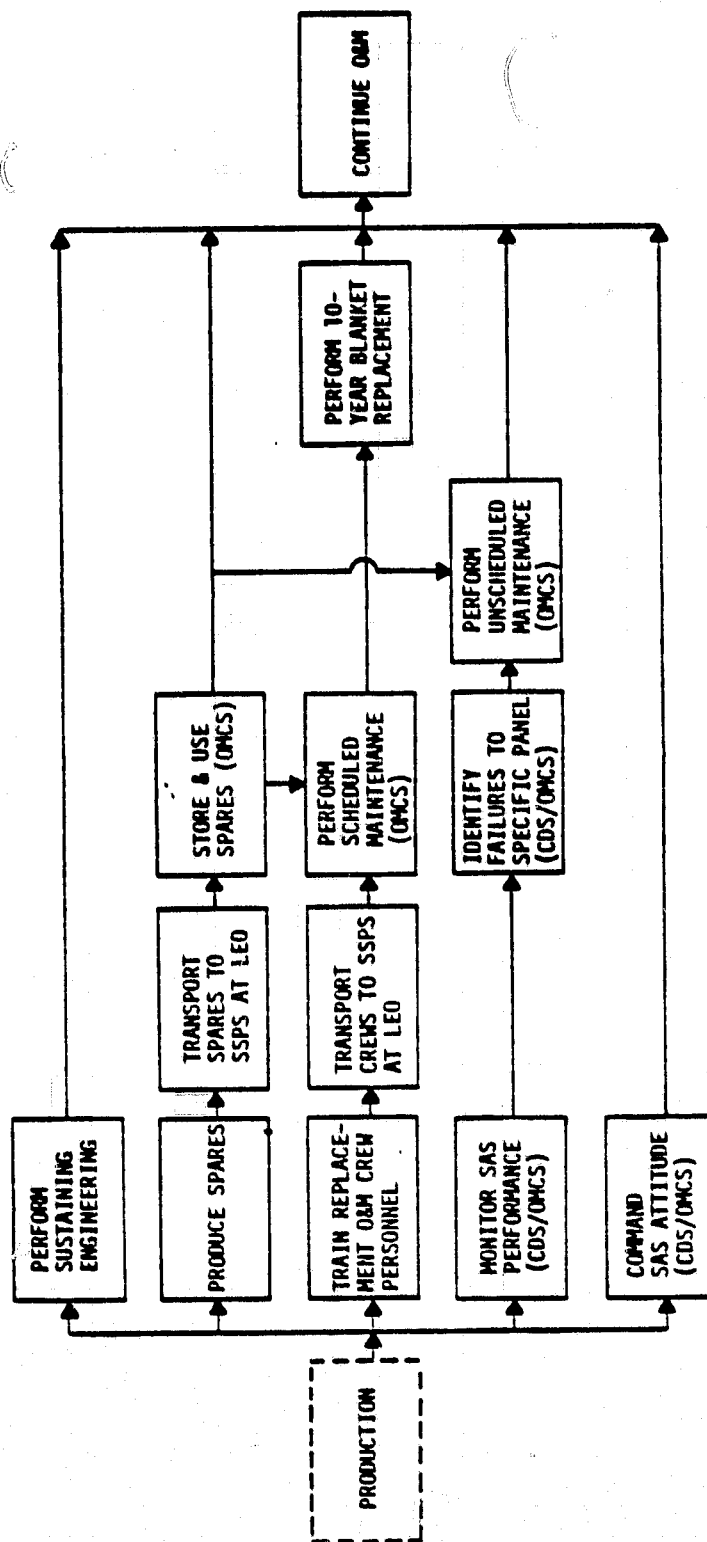


EXHIBIT 1-10. O&M FUNCTIONAL FLOW

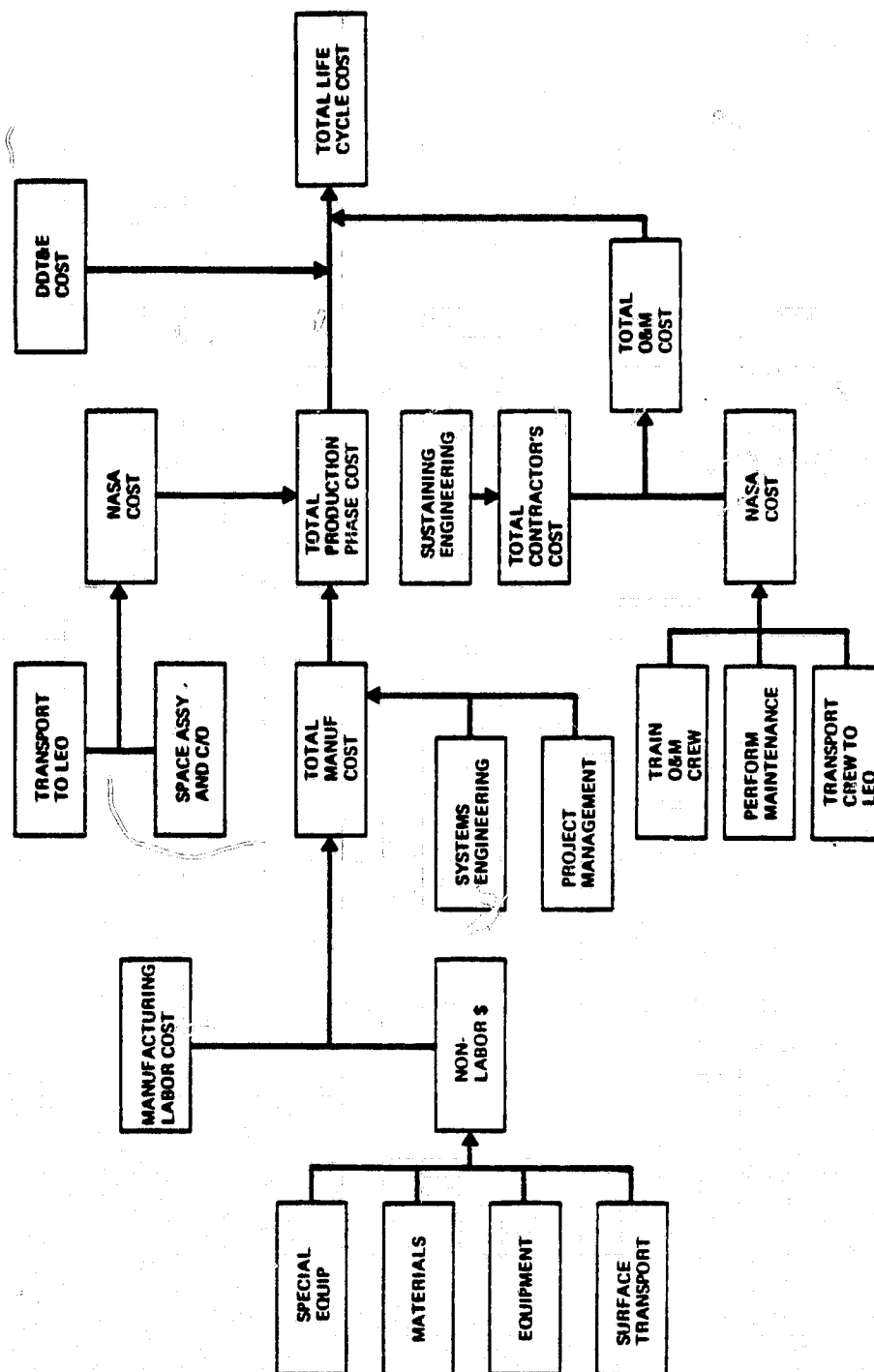


EXHIBIT 1-11. SOLAR ARRAY SUBSYSTEM LIFE CYCLE COST MODEL STRUCTURE

1.2.2.3 Subtask II-3 - Exercise the LCCM

The purpose of this task was to determine the LCC of the SAS baseline using the LCCM, and to vary the inputs to the model to assure its validity over the range of input values expected in Task III.

The LCC for the baseline SAS is discussed in detail in Section 4.0. The top level baseline LCC costs are summarized as follows:

<u>LCC PHASE</u>	<u>1980 DOLLARS IN MILLIONS</u>
DDT&E	153.9
Production Phase	439.9
O&M	160.7
TOTAL LCC	754.5

For the purpose of comparison with other space array subsystems, the cost performance values of the baseline SAS are:

		<u>\$/WATT(1980 \$)</u>
Total LCC	BOL	792
	EOL	1,569
Production	BOL	462
	EOL	914
Manufacturing	BOL	394 ⁽¹⁾
	EOL	782

(1) \$303/Watt in 1977 \$.

1.2.3 Task III - Analysis of Cost-Technology Parameters

The purpose/objective of this task was to determine the effect on the baseline LCC of varying technology parameters. Task III consisted of five subtasks:

- Subtask III-1: Establish Technology Parameters for Existing and New Programs
- Subtask III-2: Determine the Relationship of Weight and Volume to Technology Parameters
- Subtask III-3: Determine Sensitivity of Performance Parameters to Technology Parameters
- Subtask III-4: Determine Interdependencies of Physical, Performance and Technology Parameters

- Subtask III-5: Determine Relationship of Technology Parameters to Total Life Cycle Cost

While these subtasks were required to obtain the study output, they were accomplished integrally as part of the development of a subsystem performance/cost model. Accordingly, the approach for Task III is the development of the model, and the results are the model outputs.

The performance model was developed from the design procedure followed in Task I to define the baseline SAS, with, however, variable quantitative relationships inserted to replace specific design values. The relationships which were developed include radiation flux, radiation degradation, and temperature derating. The relationships were derived from telemetry and laboratory test data, design values for historical and planned programs using regression analysis and theory. The output of the performance model consists, generally, of the weights (and masses), material quantity (number of cells, substrate area), and, where required, attrition losses, or numbers of spares (affected by reliability and maintenance). These, then, are inputs to the LCCM. The LCCM provides the LCC for the particular set of input values, which represent a specific set of parameter values defining a variation in the baseline SAS design.

The performance/cost model as applied to Task III is discussed in more detail in Section 5.0. Exhibit 1-12 is a top level block diagram of the performance/cost model.

The results of Task III are the relationships of LCC versus:

- cell thickness
- blanket temperature
- cover thickness
- cell efficiency
- cell degradation
- cover degradation
- line voltage (bus)
- years between overhaul
- meantime between failure
- cell/cover unit cost

These are shown in the graphs of Exhibit 1-13 and Exhibit 1-14.

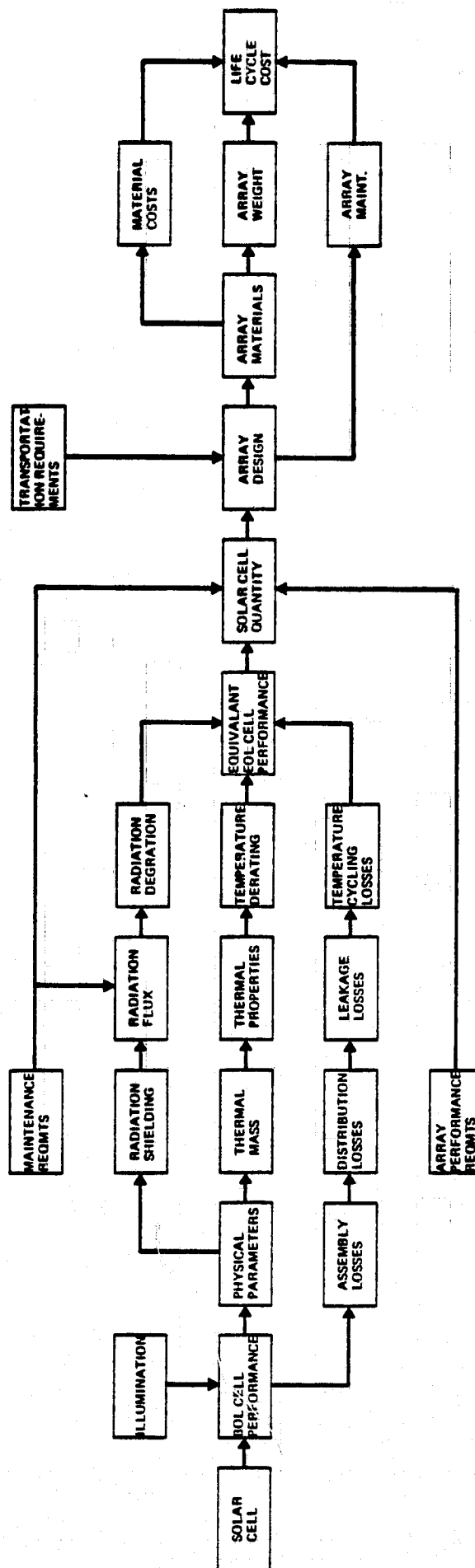


EXHIBIT 1-12. SOLAR ARRAY PERFORMANCE AND COST MODEL

1.3 Conclusions and Recommendations

This section summarizes the analyses and results of the study and presents recommendations. More detailed discussions are provided in Section 5.0 of the performance/cost model which was applied to quantify technology vs LCC, and in Section 6.0 of the quantitative results obtained for specific technology vs LCC.

1.3.1 Conclusions of the Study

Conclusions to be drawn from the study results are valid in the vicinity of the baseline under the study requirements, and the assumptions and scenarios generated in Tasks I and II. Generally these are:

- Silicon cells, planar array
- Orbit of 444 km, 56° inclination
- Shuttle transportation
- Earth manufacturing scenario
- Manual assembly in space (equipment assisted)
- Space-based maintenance includes personnel for routine maintenance
- DDT&E, program management and SE&I are "wraparound" cost factors
- \$31M/14,000 kg space transportation costs
- Cell/cover assembly costs are historical, but adjusted to 70%, recognizing the large quantity required.

It is important to note that the performance/cost model and/or data base can be easily changed to reflect variations in the above requirements, scenarios and assumptions, in effect to perform trade studies to optimize the subsystem.

Exhibits 1-13 and 1-14 of Section 1.2.3 show the relationships of the various technology areas to LCC. The following sections discuss each technology area result. Exhibit 1-15 gives the results in tabular form.

1.3.1.1 Cell Thickness vs LCC

The relationships shown on Exhibit 1-13 (a) are for three types of silicon cells: (1) conventional/historical, (2) back surface field and (3) back surface field plus thin diffused top region. The data for all three types of cells were derived from "Semi-Conductors and Semi-Metals" Volume II, Hovel, 1975, Academic Press.

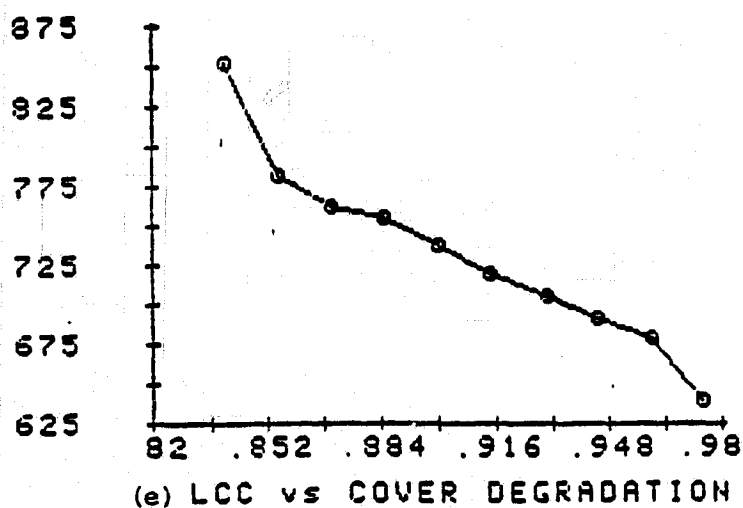
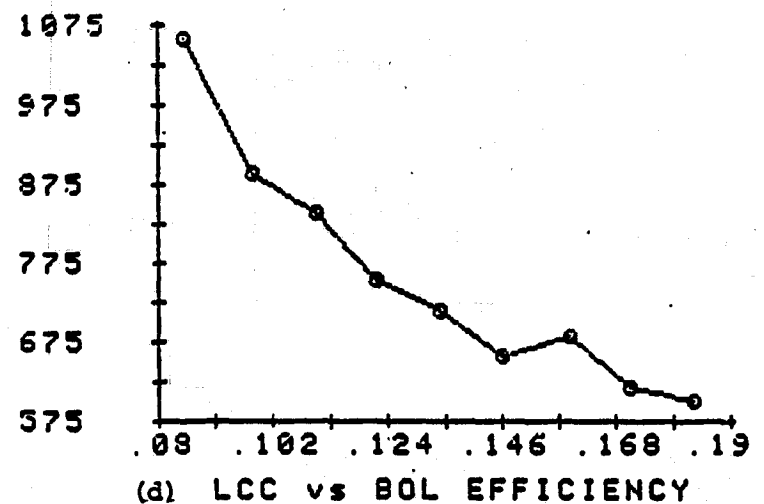
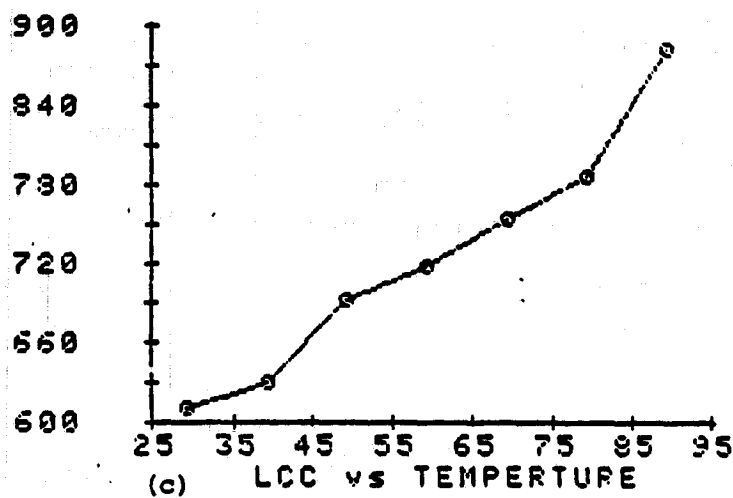
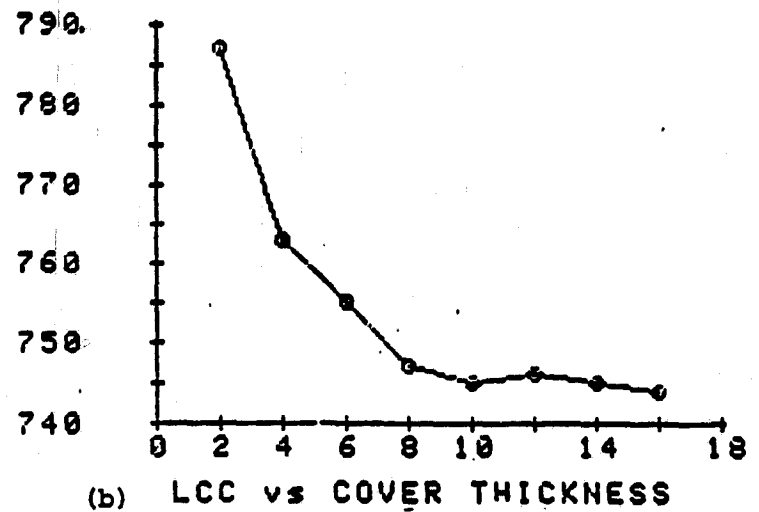
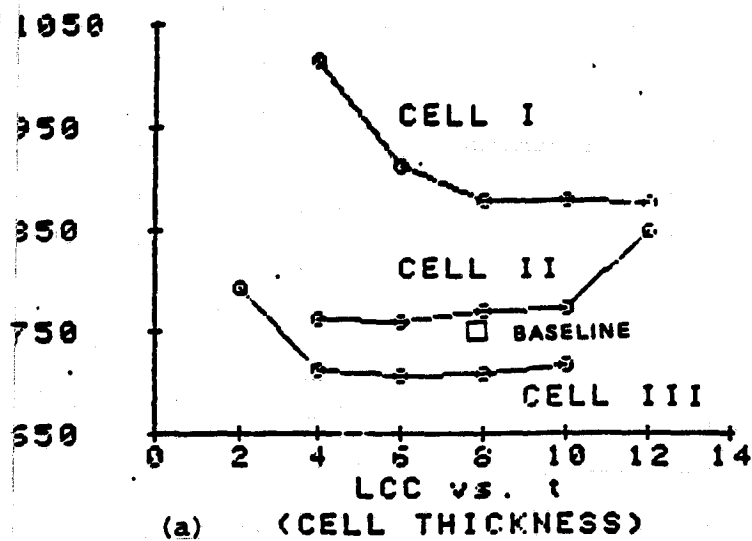


EXHIBIT 1-13. TECHNOLOGY PARAMETERS vs LCC

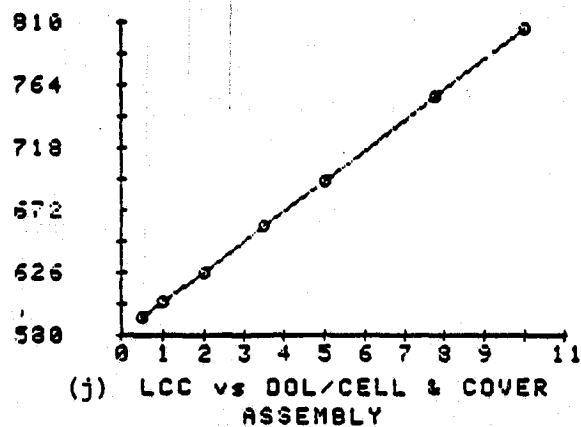
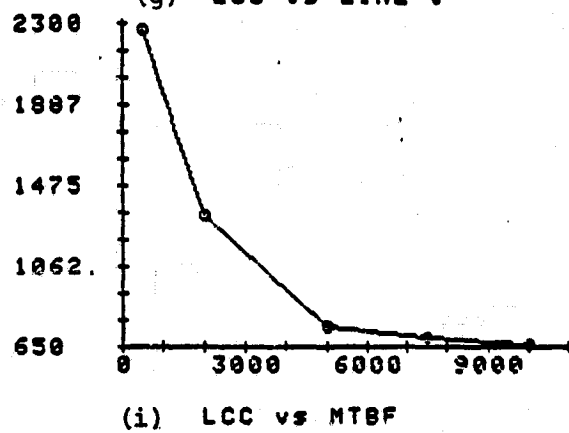
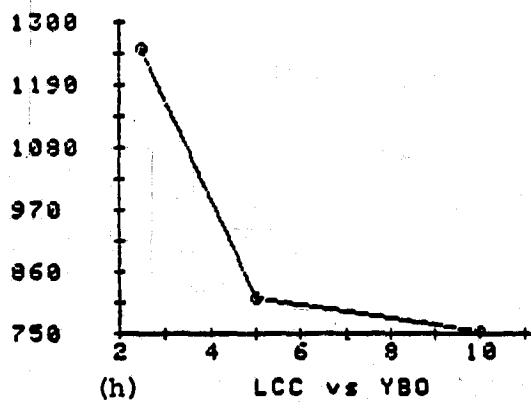
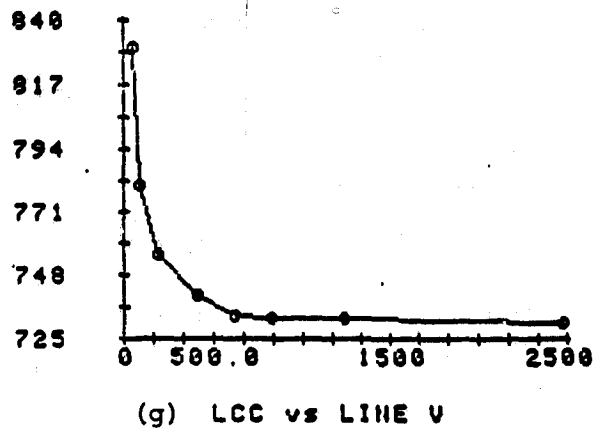
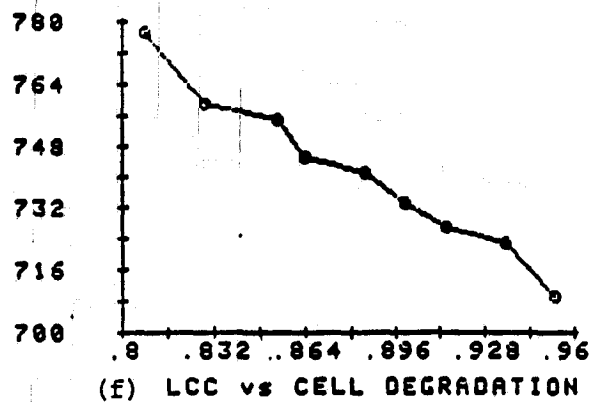


EXHIBIT 1-14. TECHNOLOGY PARAMETERS vs LCC

TECHNOLOGY AREAINFLUENCE ON LCC

CELL THICKNESS	MEDIUM/STRONG - 6 MILS OPTIMUM*
COVER THICKNESS	MEDIUM - LITTLE GAIN ABOVE 12 MILS
BLANKET TEMPERATURE	STRONG - \$3.2M/°C
CELL EFFICIENCY	STRONG - \$46M/1% CHANGE
COVER DEGRADATION	MEDIUM/STRONG - \$10M/1% CHANGE
CELL DEGRADATION	MEDIUM - \$5.4M/1% CHANGE
LINE VOLTAGE	WEAK - LITTLE GAIN ABOVE 400 VOLTS
YEARS BETWEEN OVERHAUL	WEAK - LONGER LIFE BETTER
MTBF	MEDIUM - KEEP MTBF UP, SPARES LOW
CELL COVER ASSEMBLY COSTS	STRONG - \$22M/\$ CELL COVER ASSEMBLY UNIT COST

*RESULTS ARE GIVEN FOR THREE CLASSES OF CELLS (THIS APPLIES TO BSF + THIN
DIFFUSED TOP REGION CELL ONLY).

The cell thickness relationships of 1-13 (a) all show a strong influence on LCC, and more importantly the advantages of the back field, thin diffused top region cell. For this type of cell, a thickness of 6 mils is optimum.

The deviation of the data points from a smooth curve fit are a result of the number of panels required per power channel which in turn is a result of the Shuttle payload bay dimensional constraints. The SAS baseline is plotted as a reference point ($t = 8$ mil, $\eta_{\text{BOL}} = .122$).

1.3.1.2 Cover Thickness vs LCC

The relationship shown in Exhibit 1-13 (b) for cover thickness displays a strong influence on LCC in the vicinity of four mils, a somewhat reduced influence near the baseline (eight mils), and with little gain above at 12 mils. An increasing cover thickness has three effects on LCC: (1) increased weight of array, (2) reduction of degradation rate of cell, and (3) decrease in blanket mean temperature.

1.3.1.3 Blanket Temperature vs LCC

The relationship shown in Exhibit 1-13 (c) shows a strong influence on LCC of the mean blanket temperature. This derives basically from the change in cell efficiency with temperature (\$3.2M per 1°C). The two curves (C1 & C2) reflect differences in the number of panels/channel due to shuttle transportation volume limitations.

1.3.1.4 Cell Efficiency vs LCC

The relationship shown in Exhibit 1-13 (d), as expected, shows a strong influence on LCC. In the vicinity of the baseline, the slope is \$46M per 1% change in cell efficiency (measured at BOL). The basic effect is on baseline quantities, weights, and cell unit costs. The two separate data points reflect differences in the number of panels/channel due to shuttle transportation volume limitations.

1.3.1.5 Cover Degradation vs LCC

The relationship shown in Exhibit 1-13 (e) displays a medium/strong influence on LCC. The slope in the vicinity of the baseline optical factor (.885) is about \$10M per 1% unit change of the factor. The cover unit cost variation is more than offset by the substantial reductions in weight, dimensions and number of cells in the baseline.

2.0 BASELINE

2.1 Space Services Platform System, SSPS

The SSPS has been hypothesized to create a system structure within which a Solar Array Subsystem (SAS) can be defined to provide a baseline design for cost-technology studies. The purpose of the SSPS is to provide services to varied User Systems. The User Systems may be engaged in materials processing, astronomy, solar systems and earth observation, life sciences, communications, or other operations. The User Systems may be secured to the platform or docked for servicing or short-term operations. The general configuration of the SSPS is shown in Exhibit 2-1. The subsystems of the SSPS, their functions and major interfaces are summarized in Exhibit 2-2.

2.1.1 Solar Array Subsystem, SAS

The SAS provides electrical power to the Energy Storage, Distribution and Conditioning Subsystem (ESDCS). The power is provided by a two-paddle solar array blanket assembly through a 2 axis drive/slip ring assembly. The power is fed to the ESDCS in 48 power channels at peak power levels of 10 kW and 197 volts.

2.1.2 Energy Storage Distribution and Conditioning Subsystem, ESDCS

The ESDCS, located on the Structural/Mechanical Subsystem (SMS) platform receives electrical energy from the SAS at the SAS 2-axis drive slip ring assembly output. The ESDCS provides energy storage, conditioning and distribution of power to the User Systems and to the subsystems of the SSPS.

2.1.3 Structural/Mechanical Subsystem, SMS

The SMS provides (1) the structural mounting platform for User Systems and for the SSPS subsystems, (2) drive power for the Solar Array Subsystem 2 axis/slip ring assembly, and (3) docking facilities for free flyers. The attitude of the platform is maintained by thrusters of the Propulsion & Control Subsystem (PCS), which are commanded by the Command and Data Subsystem (CDS). There are two

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^ 27, 28, 29 ^

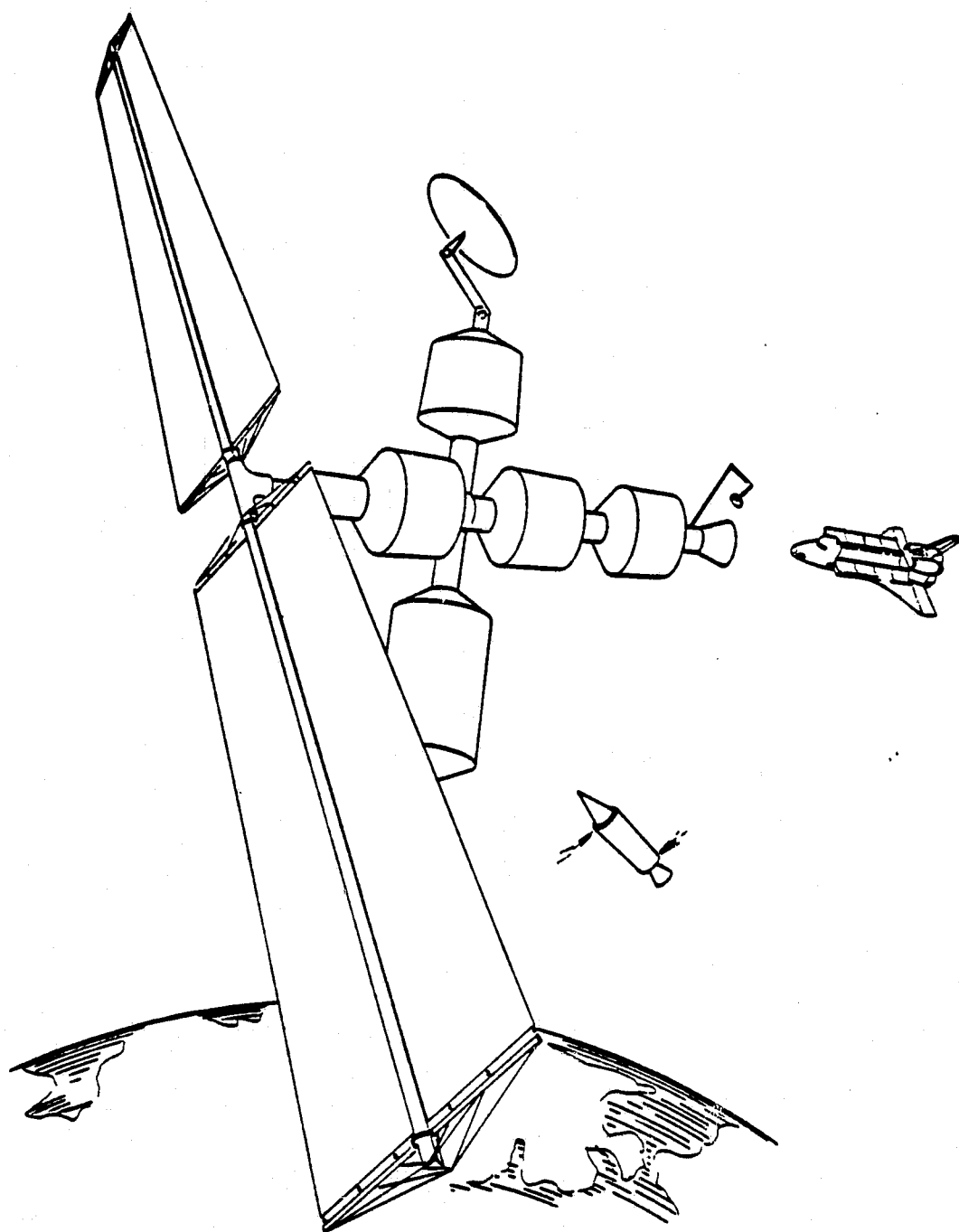
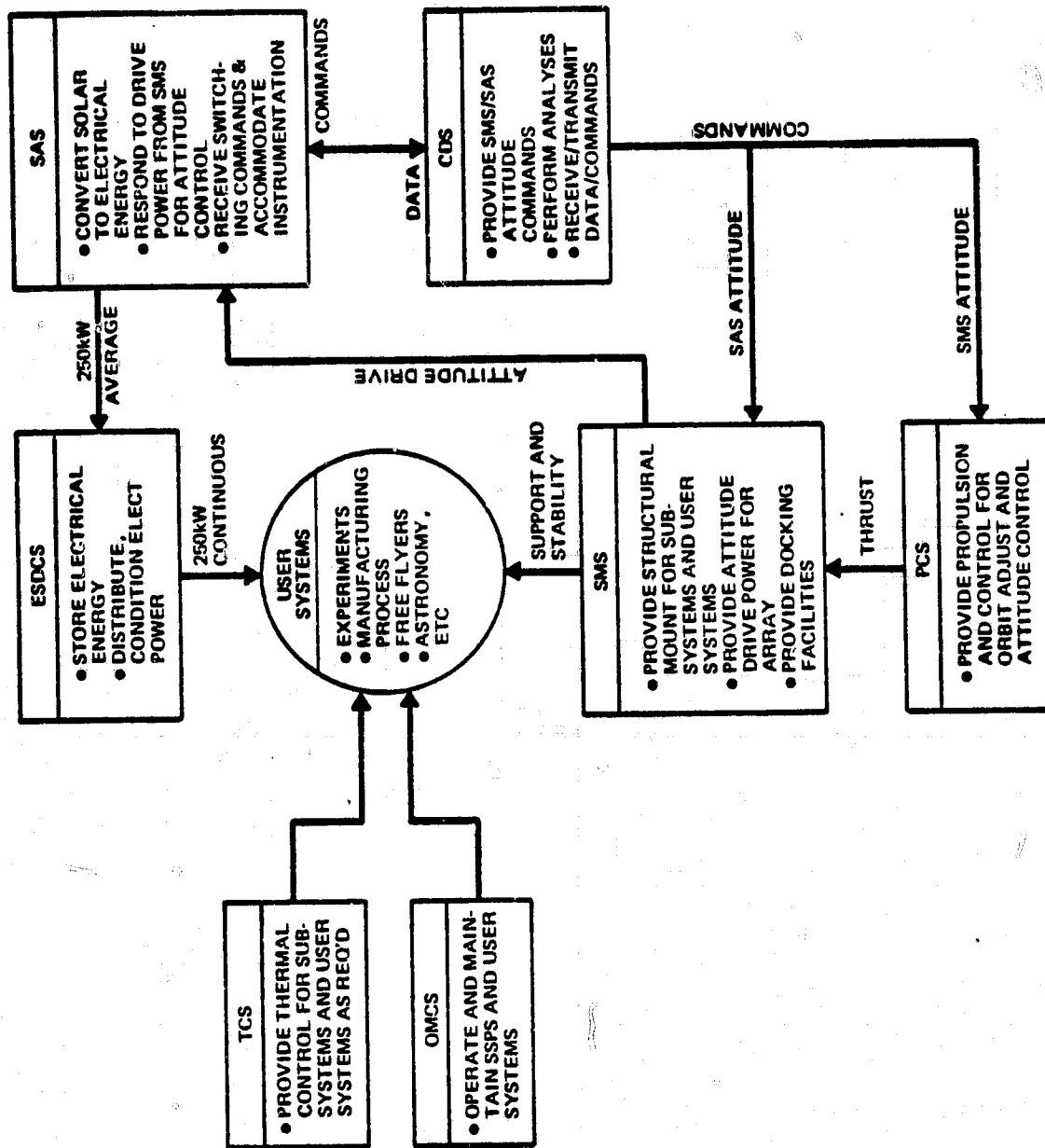


EXHIBIT 2-1. SPACE SERVICES PLATFORM SYSTEM



LEGEND:

- SAS SOLAR ARRAY SUBSYSTEMS
- CDS COMMAND AND DATA SUBSYSTEM
- SMS STRUCTURAL MECHANICAL SUBSYSTEM
- PCS PROPULSION AND CONTROL SUBSYSTEM
- OMCS OPERATIONS AND MAINTENANCE CREW SUBSYSTEM
- TCS THERMAL CONTROL SUBSYSTEM
- ESDCS ELECTRICAL STORAGE, DISTRIBUTION AND CONDITIONING SUBSYSTEM

EXHIBIT 2-2. SPACE SERVICES PLATFORM SYSTEM

interfaces of the SMS with SAS:

- structural mounting for the SAS 2 axis drive/slip ring
- mechanical drive of the SAS attitude at the input shafts of the SAS 2 axis drive/slip-ring assembly.

2.1.4 Propulsion and Control Subsystems, PCS

The PCS provides attitude control and orbit adjust thrust for the SSPS. The thrusters are mounted on the SMS platform and at the end-booms of the SAS.

2.1.5 Command and Data Subsystem, CDS

The CDS provides (1) the required attitude commands for the SMS and the SAS, (2) analyses, status reports, and corrective action based on telemetry data sensors located as required on the SSPS, SSPS subsystems and User Systems, and guidance and navigation sensors, and (3) command & data relay communications from external systems to SSPS and User Systems.

2.1.6 Operations and Maintenance Crew Subsystem, OMCS

The OMCS provides operations services and maintenance for SSPS subsystems and User Systems. The OMCS is stationed on-board the SSPS SMS platform.

2.1.7 Thermal Control Subsystem, TCS

The TCS provides thermal control capability for SSPS subsystems and User Systems as required.

2.2 Mission Scenario and System Requirements

The mission scenario and the system requirements on the SSPS and the subsystem requirements on the SAS are contained in Appendix A. The mission scenario for the SAS is summarized as follows:

- Operational 1985-1995
- LEO Orbit: 444 KM, 56° incl
- Power Output: 250 kW Continuous to Load
- Varied Angle to Sun to Maintain 250 kW to Load
- Production of Array Hardware on Earth
- Folded Blankets for Space Transport
- Space Shuttle Transport to Leo
- Astronaut Assembly and Checkout Assisted by Maneuverable Work Platforms

- Panel Level Replacement by Astronauts
- Panel Replaced When Power Output Degrades Below Design Value

The SAS system requirements are summarized in Exhibit 2-3.

2.3 Work Breakdown Structure

The baseline SAS Work Breakdown Structure (WBS) is shown in Exhibit 2-4. The WBS identifies the elements which are assembled to make up the solar array subsystem. From a project standpoint, each element represents a design package. The WBS has been developed to organize the functions and their sequencing, which include materials processing, manufacturing, integration, assembly and installation.

2.4 Solar Array Design

The baseline SAS is a two-wing planar array, with a single boom structure (one for each wing), which holds the array blankets in tension. The SAS is a fold-up array which will be shuttle transported and assembled in space.

The electrical power is bussed to the centrally located slip-ring assembly. The bus conductors are supported by a semi-circular (300°) styrofoam segment attached to the bottom of the boom. The slip ring assembly is double-gimballed to make independent the orientations and motions of the array and the user platform. The array output is held constant over the array life by varying the sun-vector/angle.

2.4.1 Electrical/Mechanical

2.4.1.1 Array Hierarchy

The array hierarchy, which is shown in Exhibit 2-5, breaks down as follows:

1 array	=	2 wings
1 wing	=	2 blankets
1 blanket	=	48 panels
1 panel	=	15 modules
1 module	=	3,150 cells (2 x 4 cm)

ORBIT PARAMETERS

- ORBIT PERIOD: 87.3 MINUTES
 - ILLUMINATION 53.7 MINUTES
 - ECLIPSE 33.6 MINUTES
- TOTAL CYCLES: 60,239 - TEN YEARS (INCL 2 LEAP YEARS)

ARRAY ENERGY REQUIREMENT

	<u>ENERGY</u>	<u>POWER</u>
• TOTAL PER ORBIT - ARRAY	431.25 kw HR	478.3 kw
- USER	225.4 kw HR	250 kw
- ENERGY STORAGE (0.672)	205.85 kw HR	228.3 kw

EXHIBIT 2.3. SYSTEM REQUIREMENTS

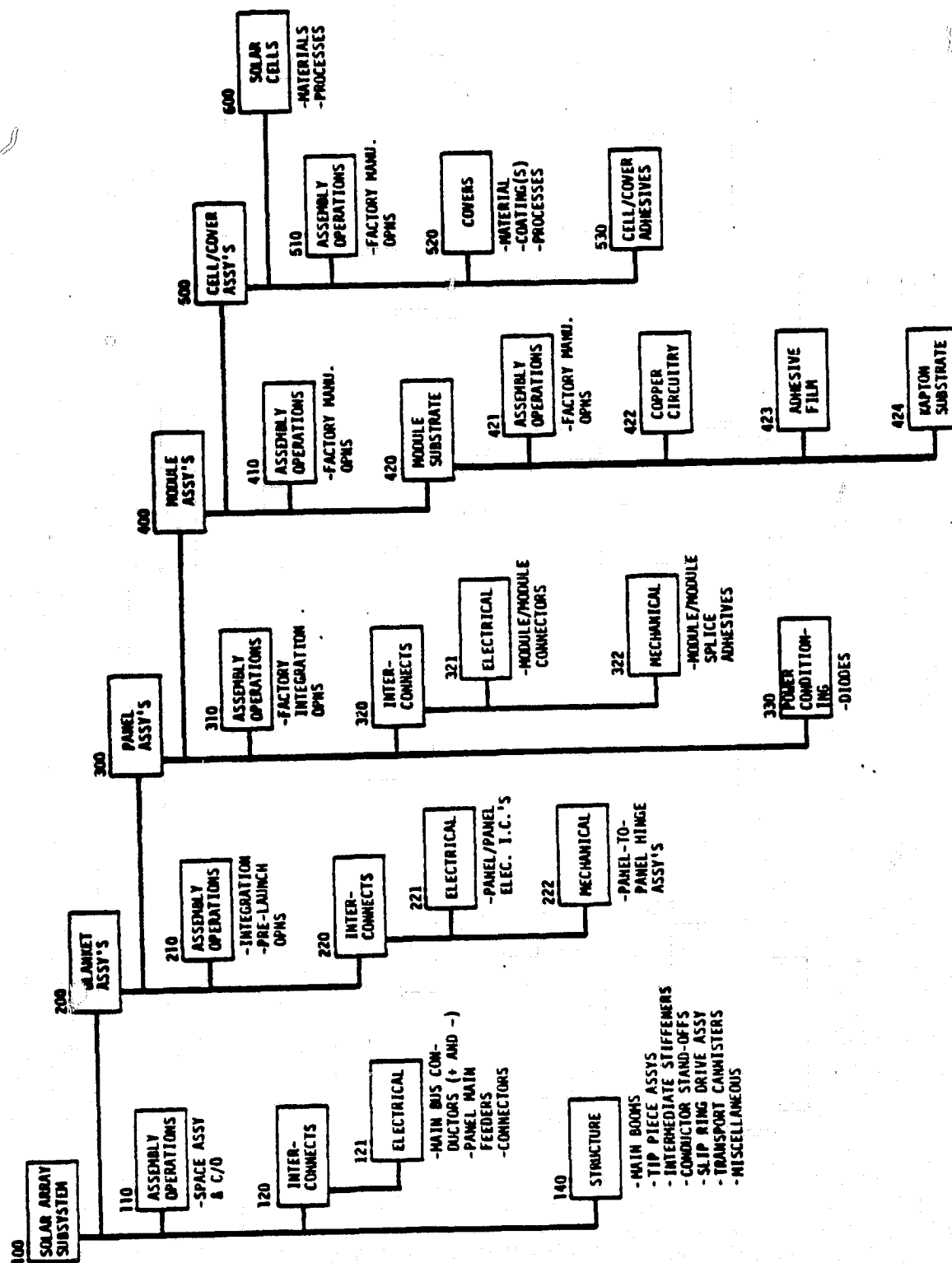


EXHIBIT 2-4. SAS WORK BREAKDOWN STRUCTURE

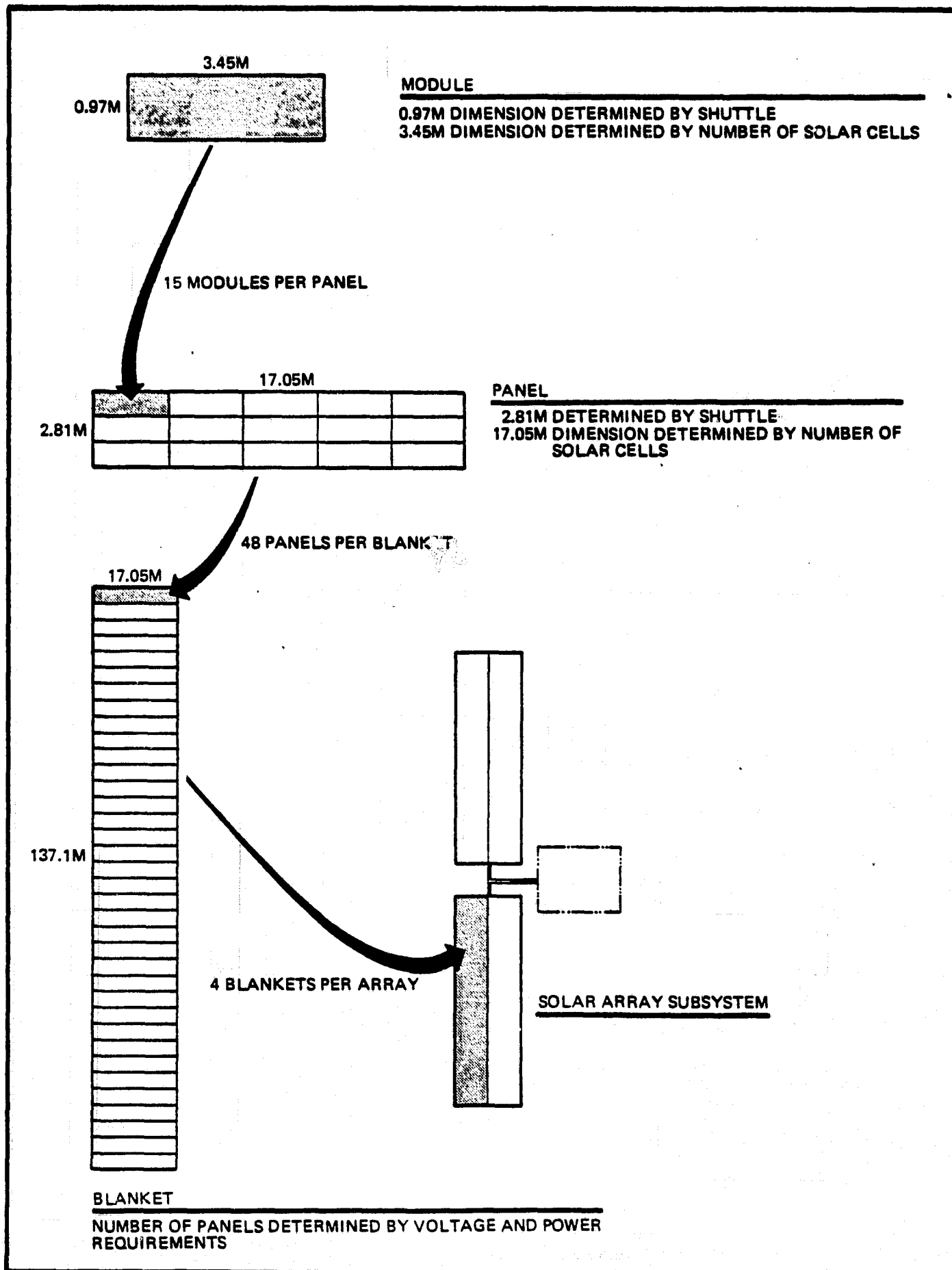


EXHIBIT 2-5. SAS HIERARCHY

2.4.1.2 Array Sizing

The sizing of the array hierarchy is summarized below.

- Wing

Length = 152.1 m

Width = 31.4 m

- Blanket

Length = 137.1 m

Width = 15.2 m

- Panel

Length = 15.2 m

Width = 2.81 m

- Module

Length = 3.08 m

Width = .97 m

Note: Panel dimensions include 5 cm overlap at module/module interfaces.

2.4.1.3 Array Blanket

The array blanket, as shown in Exhibit 2-6, consists of 12 electrical channels per blanket. Each channel provides 10 kW of power at 198.0 VDC and consists of 4 panels each providing 2.5 kW at 49.5 VDC. The main bus conductor for each blanket consists of 12 pairs of conductors (1 pair/channel) which provide the electrical distribution between the blanket and the slip-ring assembly.

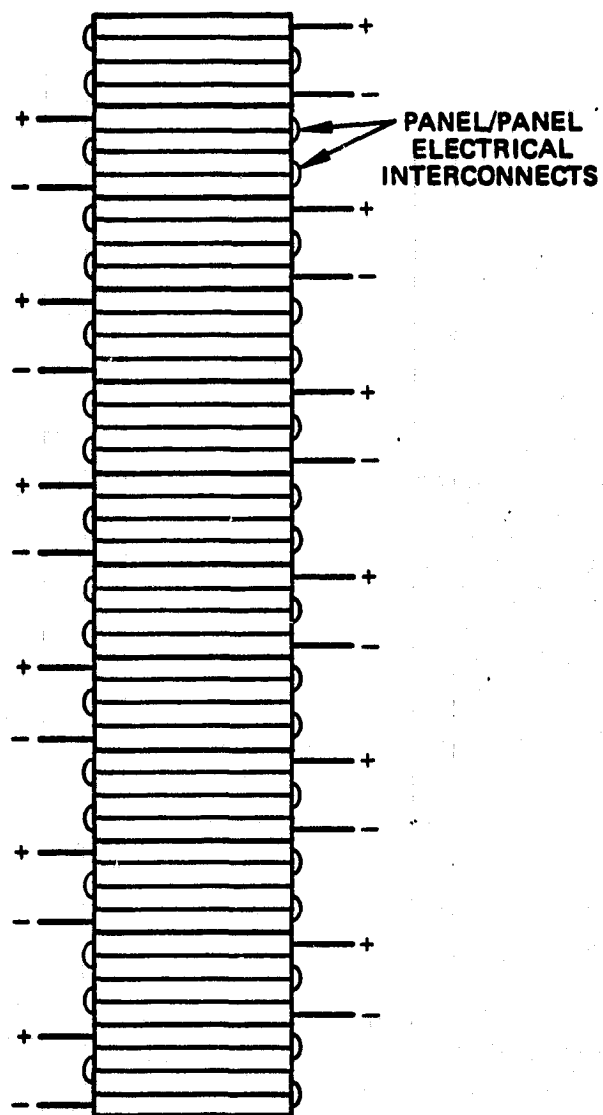
2.4.1.4 Array Panel

The array panel, as shown in Exhibit 2-7, physically consists of 15 modules arranged in a 5 x 3 configuration. Electrically, the panel consists of one 1/4-module connected in parallel and thirty 1/4-modules connected in series. Each 1/4 module consists of 5 cells in series and 315 cells in parallel and provides 83.5W at 1.65 VDC. The total module consists of 3150 cells, with a minimum of three cells in parallel providing the basic electrical building block.

2.4.1.5 Module Assembly Cross Section and Layout

The module assembly cross section, defined in Exhibit 2-8, consists of the following:

12 CHANNELS/BLANKET
198V@10,017W/CHANNEL

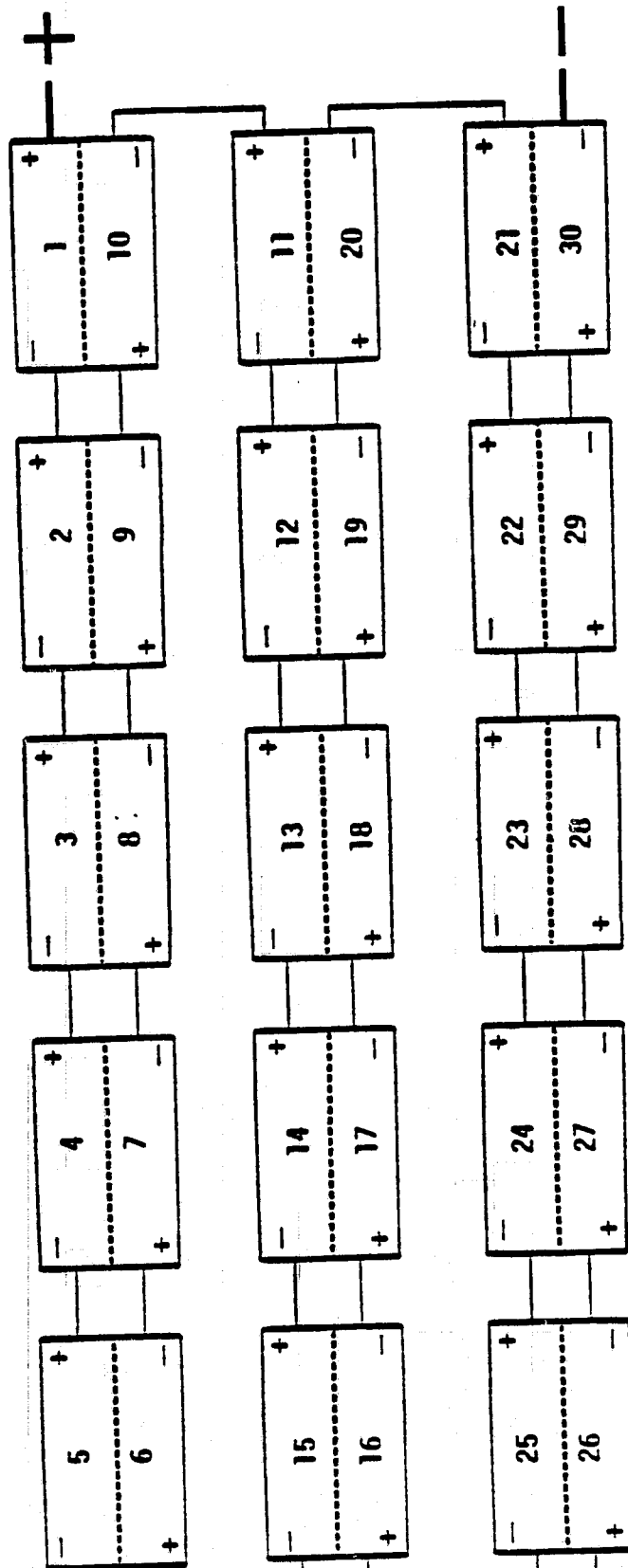


4 PANELS/CHANNEL
49.5V@2504W/PANEL

EXHIBIT 2-6. ARRAY BLANKET

1/2 MODULE
1.65V@83.5W

ARRAY PANEL (16 MODULES/PANEL)



30 X 1/2 MODULE IN SERIES
1 X 1/2 MODULE IN PARALLEL

MODULE/MODULE
ELECTRICAL INTERCONNECTS

EXHIBIT 2-7. ARRAY PANEL

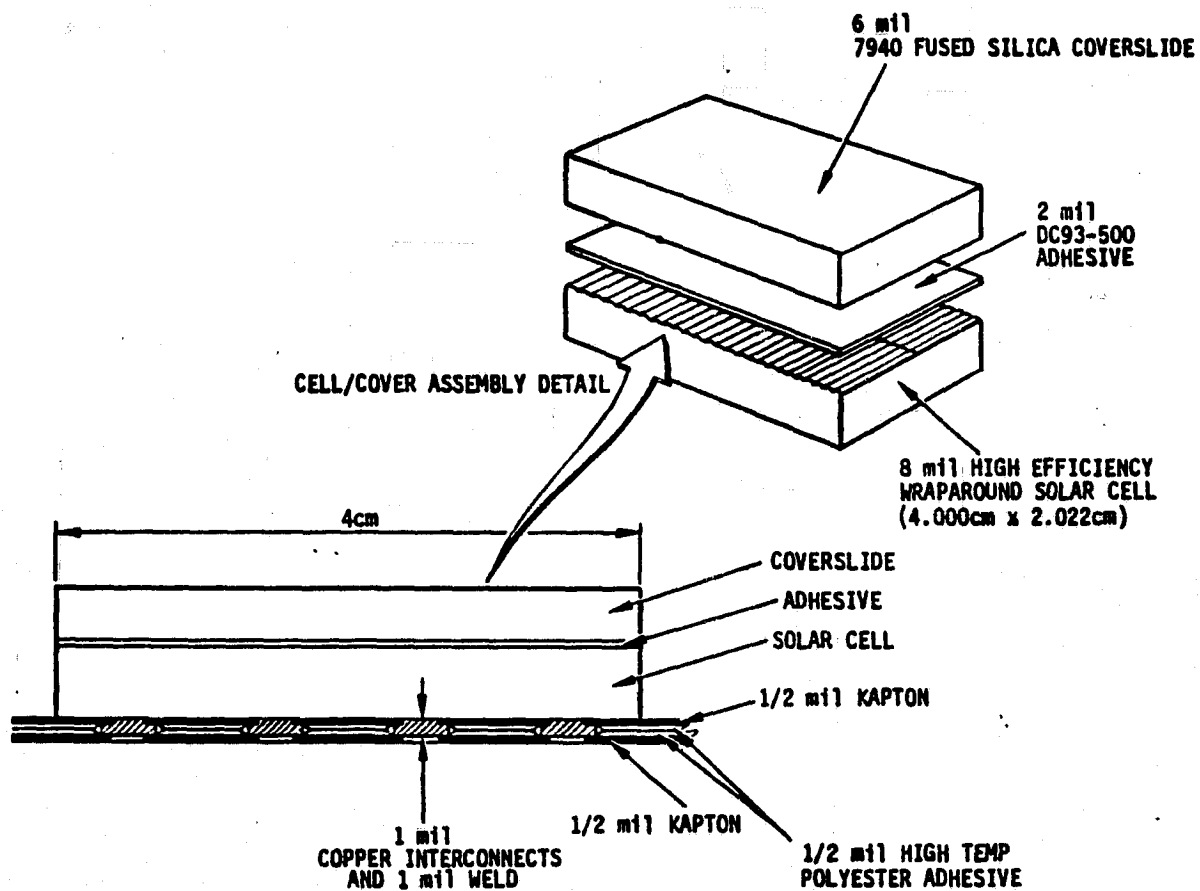


EXHIBIT 2-8. MODULE CROSS SECTION

- Solar Cell

2.022 x 4.000 cm, wraparound contact, 8 mil silicon, 2 ohm-cm AMO base resistivity, 12.2% glassed efficiency, 28°C ambient, Ta_2O_5 anti-reflective coating

- Cell Cover

2.022 x 4.000 cm, 6 mil fused silicon, uv filter, 300 μm filter cut-on

- Cover Adhesive

2 mil DC-93-500

- Substrate

Laminated printed circuit, 33% area, 1 mil copper rolled annealed interconnect. Insulation is two sheets of 0.5 mil kapton/0.5 mil high-temperature polyester adhesive.

The cells are welded to the copper interconnect circuitry through the top layer of kapton, which together with the lower layer, form a kapton-copper-kapton sandwich. Exhibit 2-9 shows the copper interconnect network with one cell overlaid in dashed lines to give position relative to the copper circuitry. The per-cell module packing factor is 0.91 based on a space of 0.13 cm between cells.

As stated in 2.4.1.4, each panel consists of 15 modules. The module consists of 3,150 cells arranged in a 40 x 81 pattern, with 90 blank cell spaces. The long dimension of the cell corresponds to the long direction of the module.

2.4.1.6 Electrical Interconnects

The basic pattern for the solar cell interconnects within the substrate is shown in Exhibit 2-9. The substrate pattern consists of 5 series connected groups of 3 cells connected in parallel. The electrical connection patterns for module/module and panel/panel interconnects as shown in Exhibits 2-7 and 2-6 respectively.

2.4.1.7 Mechanical Interconnects

The interconnects, module-to-module (which form the panels), panel-to-panel (which form the blankets), and blanket-to-tip piece assembly (to form the array), are shown in cross-section detail in Exhibit 2-10. The tip-piece assembly is part of the array structure and is discussed in Section 2.4.2.

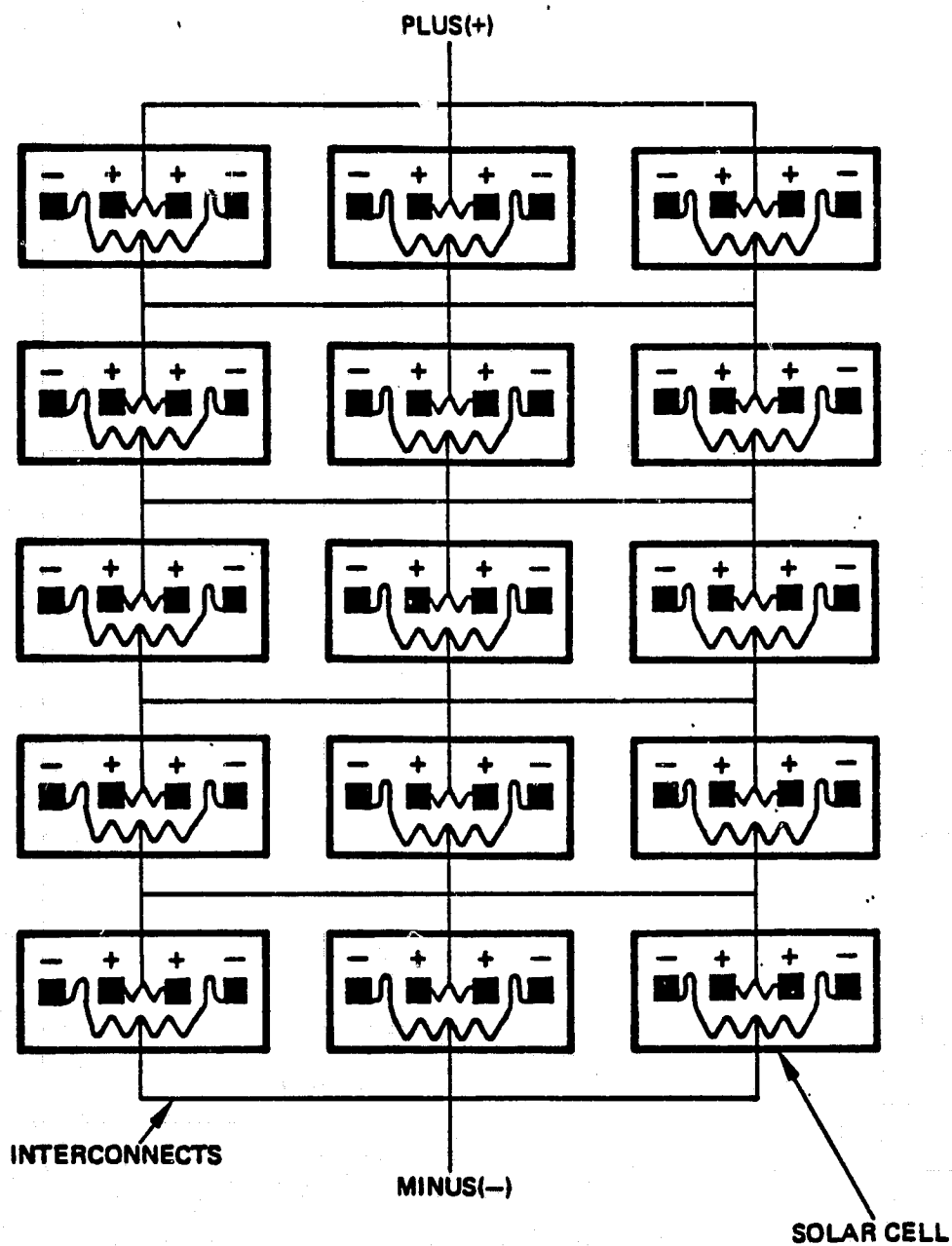
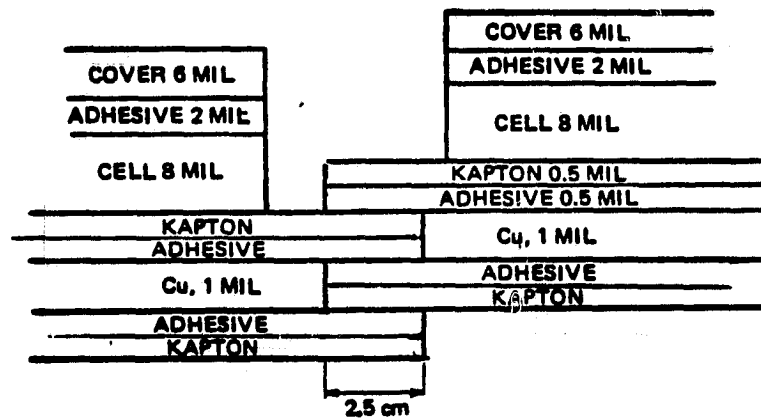
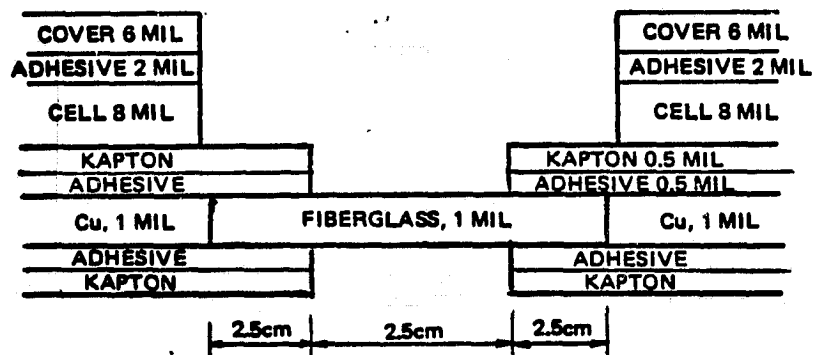


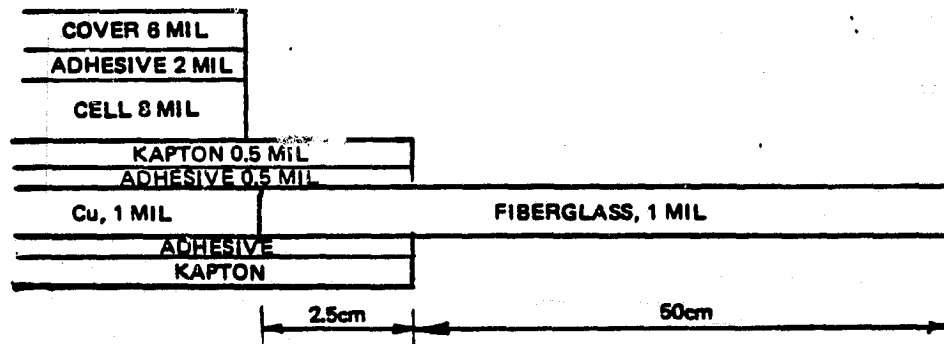
EXHIBIT 2-9. SOLAR CELL INTERCONNECTS BASIC PATTERN, 3 CELLS IN PARALLEL, 5 CELLS IN SERIES



Module/Module Interconnect



Panel/Panel Hinge Interconnect



Blanket/Tip Piece Interconnect

(NOT TO SCALE)

EXHIBIT 2-10. CROSS SECTION DETAILS, MECHANICAL INTERCONNECTS

2.4.2 Structural

The structural design assumes an astromast boom and with tip-piece assemblies for tension, and a two-axis (pitch and roll) slip-ring/drive assembly. The general layout is shown in Exhibit 2-11.

2.4.2.1 Requirements and Assumptions

The requirements and assumptions which apply to the structure are:

- 2-axis drive
- maximum angular acceleration (in pitch and roll), $\dot{\alpha} = 1.8 \times 10^{-5}$ radians/s²
- maximum bend angle, $\theta = 10^\circ$ under 0.01G force applied at outboard tip
- first natural frequency, $\omega_1 = 0.04$ radians/s
- ratio of compressive preload to critical buckling load, $P/P_{cr} = 0.3$ (NAS TN D-8376)
- ratio of blanket mass to boom mass, $\bar{M} = 6$
- aluminum booms, $r = 51$ cm
- mass of tip piece \ll mass of boom $M_{tp} \ll M_b$
- length of each boom, for baseline,
 $l_b = \text{blanket length} + 7 \text{ meters}$
 $= 144 \text{ m}$

2.4.2.2 Design

Using the relationship for bending stiffness in NAS TN D-8376

$$EI = \frac{M_b l^3 \omega^2}{\beta^4} = 2.43 \text{ kg/cm}^2$$

The critical buckling load,

$$P_{cr} = \frac{\pi^2 E I}{l^2} = 197.32 \text{ kg}$$

Therefore, for a $P/P_{cr} = 0.3$,

$$P = 65.8 \text{ kg}$$

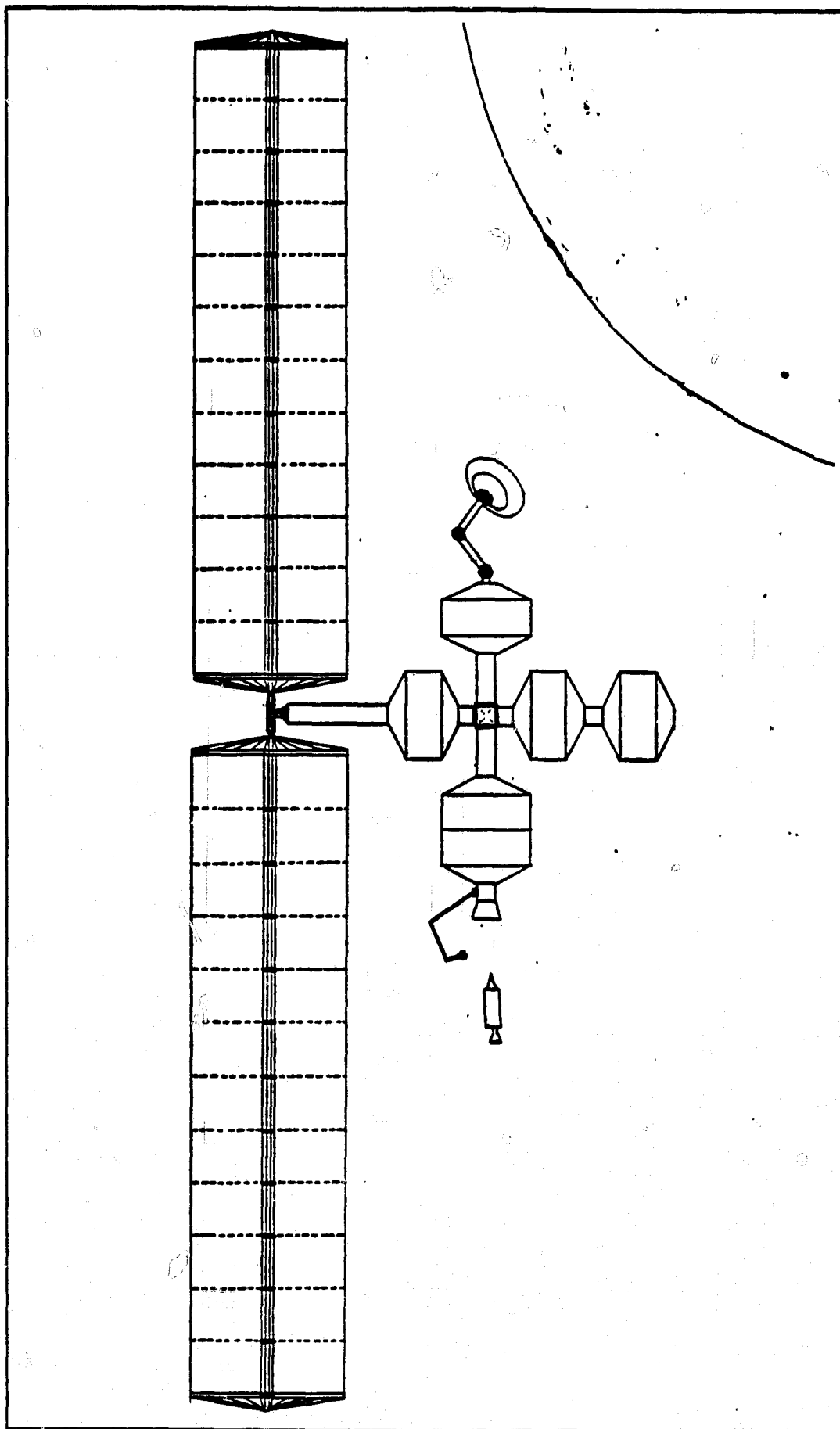


EXHIBIT 2-11. SPACE SERVICES PLATFORM SYSTEM

For $F = 0.01G$ load at the tip of the boom, the bend angle,

$$\theta = \frac{Fl^2}{2EI} + \frac{M_b(0.01)^2}{6EI} = 0.2^\circ,$$

which is well within the 10° constraint.

Using an Astro Research Corporation document*, the boom longerons (aluminum, solid cross-section) will have a cross-section area,

$$A = \frac{EI}{1.5Er^2} = 0.90 \text{ cm}^2.$$

The weight of each boom,

$$W_b = 3f \rho A l = 535 \text{ kg}.$$

The remaining structural components of the SAS were developed to the point of achieving a reasonable design concept. The structural details are shown in Exhibits 2-12 through 2-16.

To provide for varying the baseline array dimensions and weights, an analog relationship for the structure weight was derived:

$$W_{str} = \frac{W_b}{W_b(B/L)} \times 9465 \left(\frac{1}{150} \right)^3 + 154 \frac{N_{CH}}{48}$$

Where

W_{str} = structure weight, total

W_b = weight of boom

$W_b(B/L)$ = weight of baseline boom

l = length of boom

N_{CH} = number of power channels.

The detailed weight statement for the structure is shown in Exhibit 2-17.

*"Strength and Efficiency of Deployable Booms for Space Applications,"
R. F. Crawford, April, 1971.

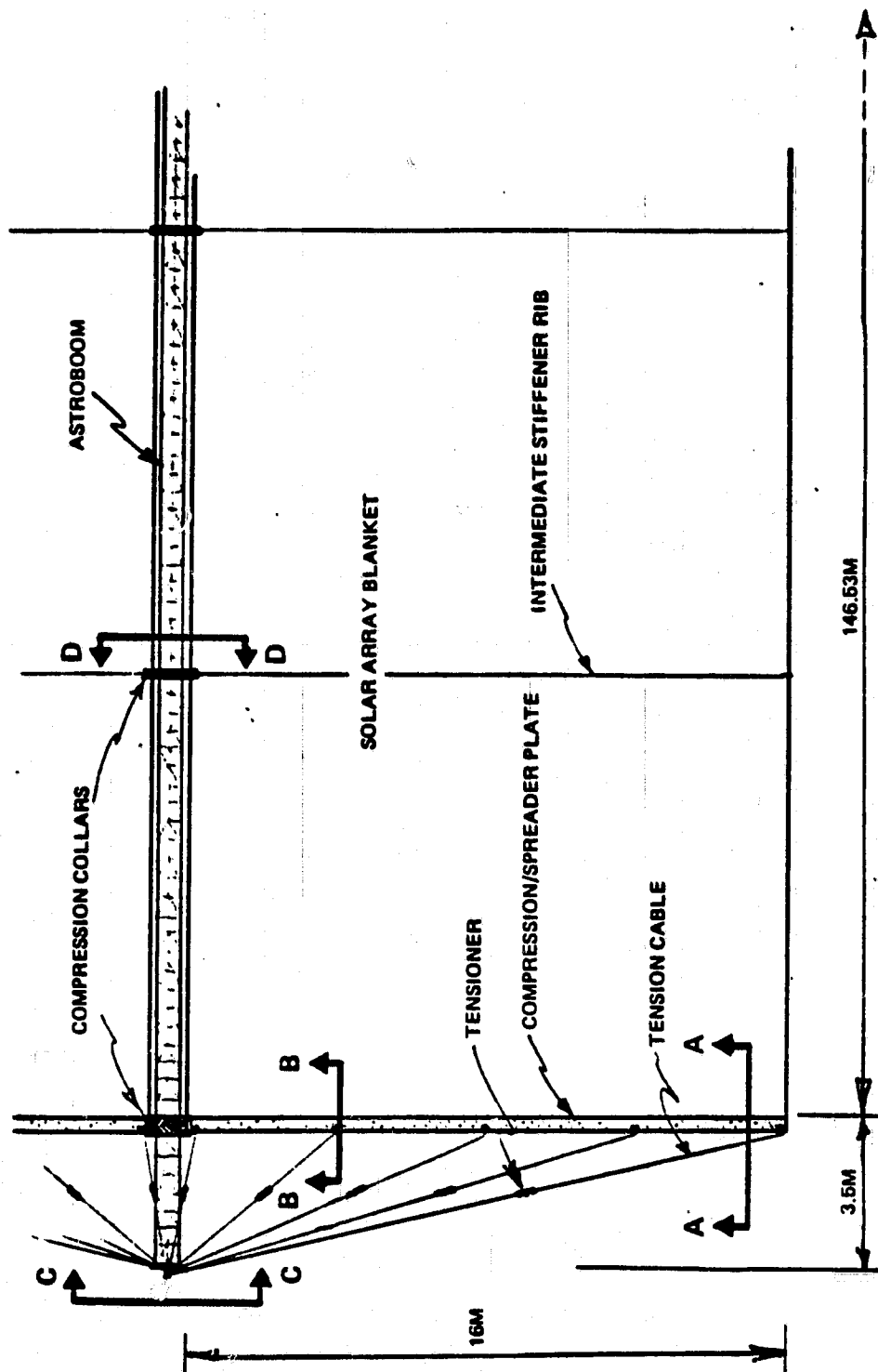
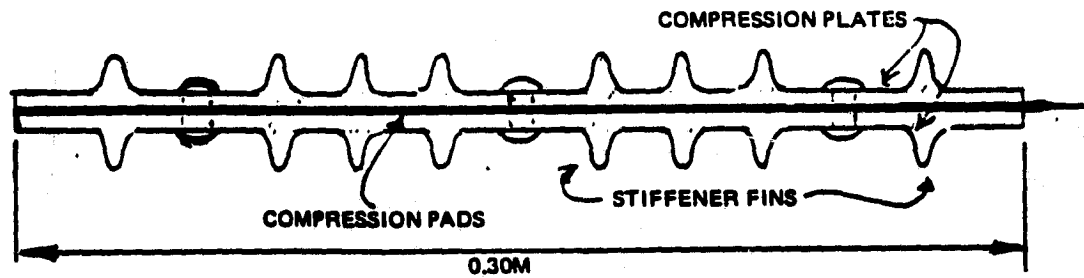
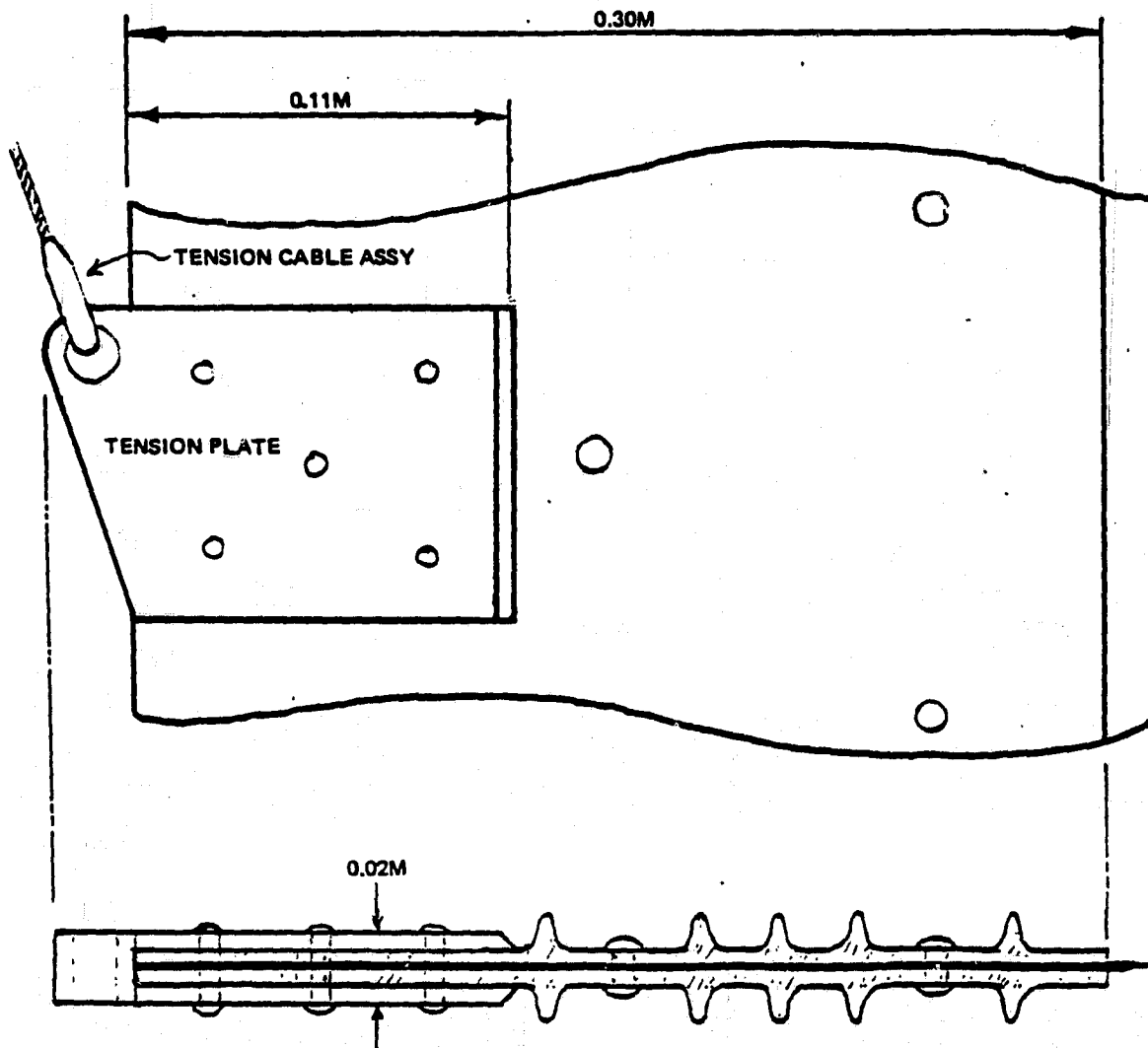


EXHIBIT 2-12. OUTBOARD END TIP ARRANGEMENT



VIEW A-A



VIEW B-B

EXHIBIT 2-13. COMPRESSION PLATE AND TENSION PLATE DETAILS

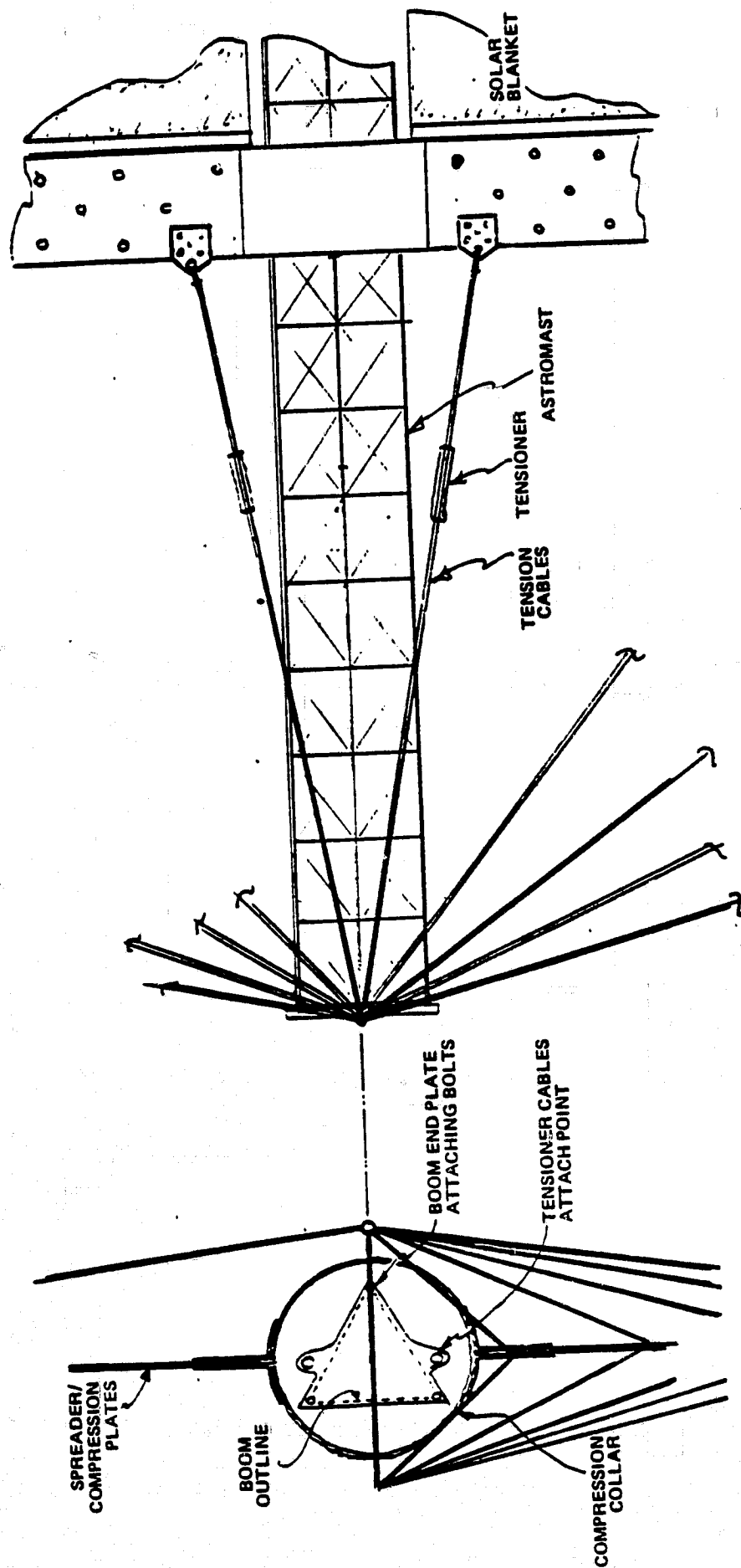


EXHIBIT 2-14. OUTBOARD END TIP PIECE DETAIL

VIEW C-C

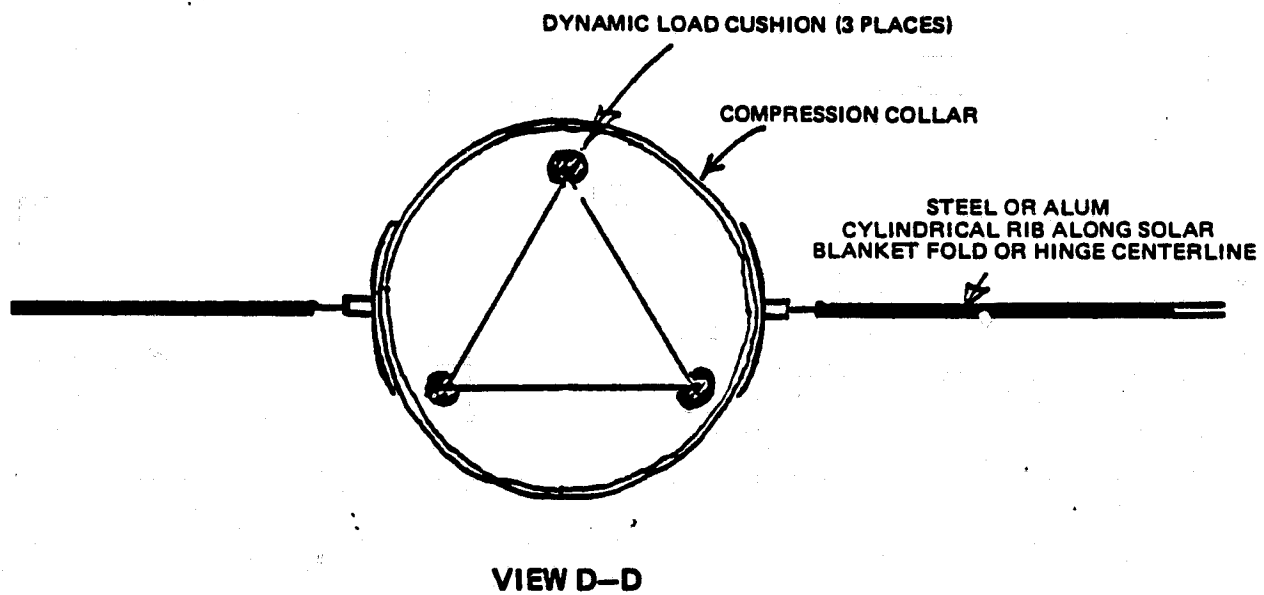


EXHIBIT 2-15. INTERMEDIATE STIFFENER RIB COLLAR DETAIL

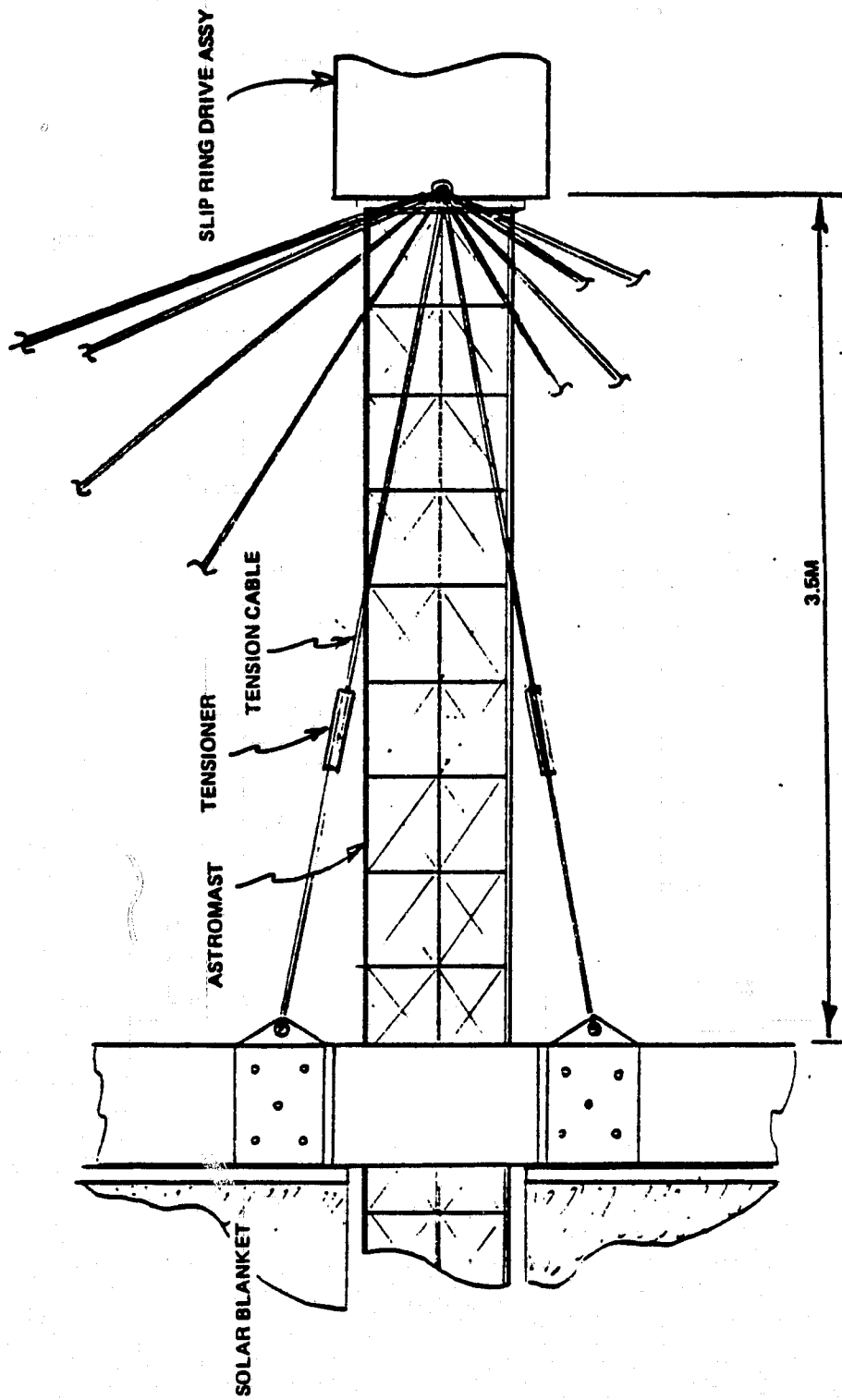


EXHIBIT 2-16. DRIVE END TIP PIECE

<u>STRUCTURAL ASSEMBLY ITEM</u>	<u>DESCRIPTION (BASELINE)</u>	<u>WEIGHT (BASELINE) kg</u>
● Main Booms, Astromasts (2)	Alumin Longerons, 50.8 cm. Dia. (Circum Circle), 144 m. Long	1,070.00
● Main Boom Transport Cannisters (2)	Shuttle Compatible (assume 10% of boom weight)	107.00
● Slip Ring Drive Assembly (1)	Not Specified	7,046.00
● Boom End Plates (4)	Alumin., Triangular shape, (1x46x40 $\frac{1}{3}$ 2) cm ³ ; 2685 KG/m	9.89
● End Plate Tension Posts (4)	Steel, 1 m. long, 1.9 cm. Dia.; 7972 KG/m	9.08
● Compression Plates (16)	Alumin. (0.5x15x1600) cm ³	515.52
● Tension Plates (40)	Alumin. (1.0x11x10) cm ³	11.81
● Tension Cables W/Eyes and Tensioners (80)	Steel Piano Wire	20.00
● Tip Piece Compression Collar Assemblies (4)	Alumin. 1.0 cm x 75cm Dia. x 50 cm long.	130.44
● Intermediate Stiffener Ribs (44)	Steel Rods, 0.5 cm Dia. 16 M. Long	110.06
● Dynamic Load Cushions (78)	Plastic (Styrene), Nylon Straps	7.80
● Main Bus Conductor Stand-Offs (48)	Plastic (Styrene), Nylon Straps	20.00
● Main Bus Conductors	--	525.00
● Miscellaneous Hardware	--	20.00
TOTAL		9,602.60

EXHIBIT 2-17. SAS STRUCTURE WEIGHT STATEMENT.

2.5 Array Summary

2.5.1 Performance Summary

The performance of the baseline solar array is summarized in Exhibit 2-18. It should be noted that the array has been sized based upon a worst-case analysis of minimum power and voltage, which occur at minimum illumination, and maximum illumination respectively. For this reason, the minimum array current is not included in the summary.

2.5.2 Weight Statement

The baseline weight statement is shown in Exhibit 2-19. The panel level electrical interconnects consist of series interconnects between the $\frac{1}{2}$ modules. The weight of the mechanical interconnects between modules (e.g., module overlap) is negligible. At the blanket level, the mechanical interconnects consist of the folding material between the panels. There are two compression plate cushions, one at each end of the blanket. The main bus at the array level consists of 12 pairs of conductors per blanket. The total structure weight includes the weight of the slip ring.

2.5.3 Array Table

The baseline array totals are summarized in Exhibit 2-20. All totals are for EOL performance. For BOL performance, (952.6kW and 210.6 VDC) the power density is 114.3 W/M^2 and the power/weight ratio is 52.3 W/Kg.

BASELINE SOLAR ARRAY PERFORMANCE

	<u>VOLTAGE (MIN)</u>	<u>POWER (MIN)</u>
SOLAR CELL	.33 V	.053 W
1/2 MODULE	1.65 V	83.5 W
PANEL	49.5 V	2,504 W
CHANNEL	198.0 V	10,017 W
BLANKET	198.0 V/CHANNEL	120.2 kW
WING	198.0 V/CHANNEL	240.4 kW
ARRAY	198.0 V/CHANNEL	480.8 kW

ARRAY REQUIREMENTS	180 V/CHANNEL (MIN)	480.0 kW
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EXHIBIT 2-18

ELEMENT	WEIGHT (KG)
PANEL LEVEL	
MODULES (15/PANEL)	42.48
ELECT. INTERCONNECTS	0.75
TOTAL EACH PANEL	43.23
BLANKET LEVEL	
PANELS (48/BLANKET)	2075
MECHANICAL INTERCONNECTS	751
COMPRESSION PLATE CUSHIONS	128
ELECT. INTERCONNECTS	31
TOTAL EACH BLANKET	2985
ARRAY LEVEL	
BLANKETS (4/ARRAY)	11,940
STRUCTURE (INCL. SLIP-RINGS)	7778
MAIN BUS CONDUCTORS	656
TOTAL FOR ARRAY	20,374

EXHIBIT 2-19. BASELINE WEIGHT STATEMENT

SOLAR ARRAY TOTALS

TOTAL CELLS	=	9.0720 x 10⁶
POWER	=	480.8 kW
AREA	=	9350 M²
POWER DENSITY	=	51.42 W/M²
WEIGHT	=	20,374 KG
POWER/WEIGHT RATIO	=	23.60 W/KG

EXHIBIT 2-20. SOLAR ARRAY TOTALS

3.0 FUNCTIONAL FLOWS

The top flow diagrams for DDT&E, Production, and Operations and Maintenance are shown in Exhibits 3-1, 3-2 and 3-3. Although the DDT&E cost estimate was based on 35% of the production costs (derived from historical program costs), a breakdown of DDT&E functions is provided for completeness and for possible future analysis; for example, the achievement of various array reliabilities would affect the design and testing costs.

It should be noted that the production phase includes transportation to space and assembly and check-out in space. The rationale here was that "buy-off" as operationally ready of the SAS as a subsystem would not occur until a final check-out of the complete and functioning assembly was accomplished. However, as discussed in Section 4.0, the space transportation and assembly and check-out are assumed to be NASA incurred costs. More detailed functional flows in the production phase are provided in exhibits as follows:

<u>FUNCTION</u>	<u>EXHIBIT</u>
Cell/Cover Assembly	3-4
Module Substrate Assembly	3-5
Module Assembly	3-6
Panel Assembly	3-7
Blanket Assembly	3-8
Space Assembly and Checkout	3-9

In the O&M flow (Exhibit 3-3) for the baseline, the "produce spares" block is null since the required number of spares (panels) are assumed to be manufactured during production. However, this could be subject to trades analysis and therefore the function has been included for completeness.

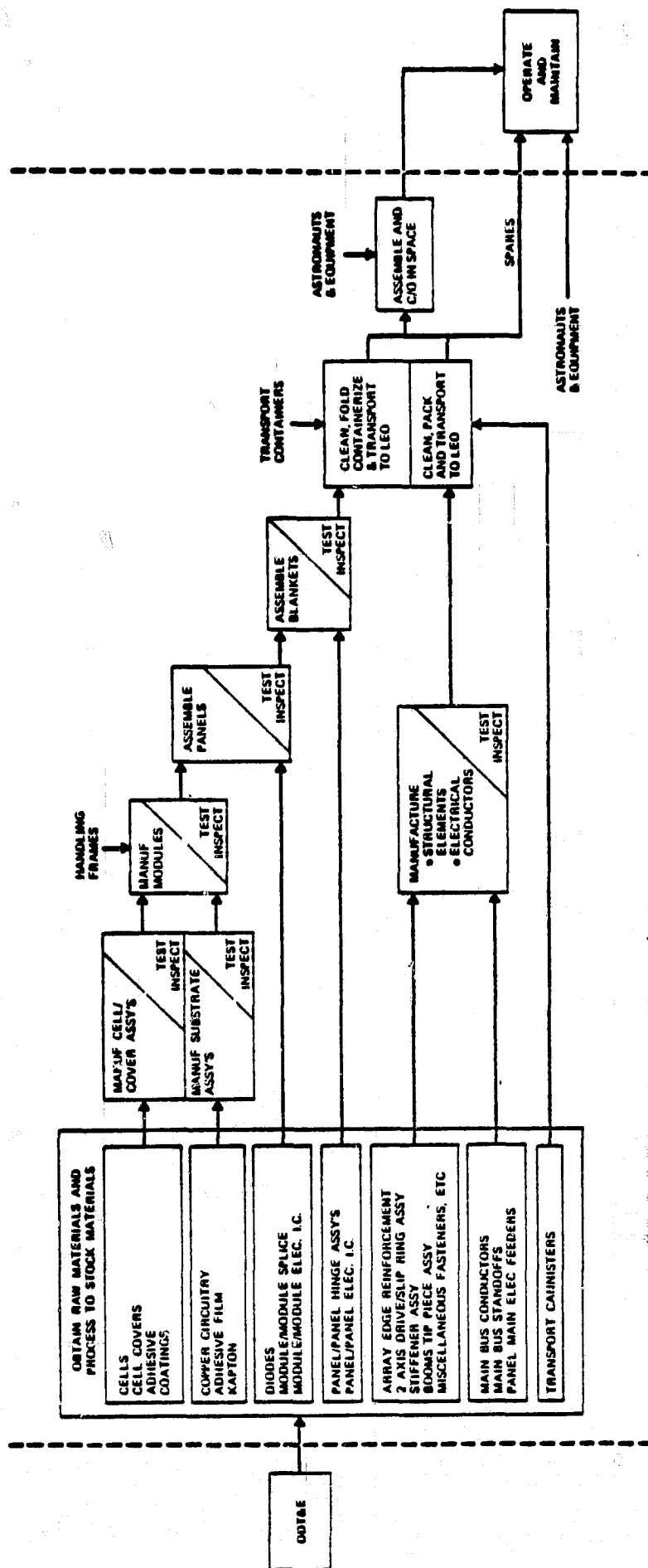


EXHIBIT 3-2. SOLAR ARRAY SUBSYSTEM FLOW.

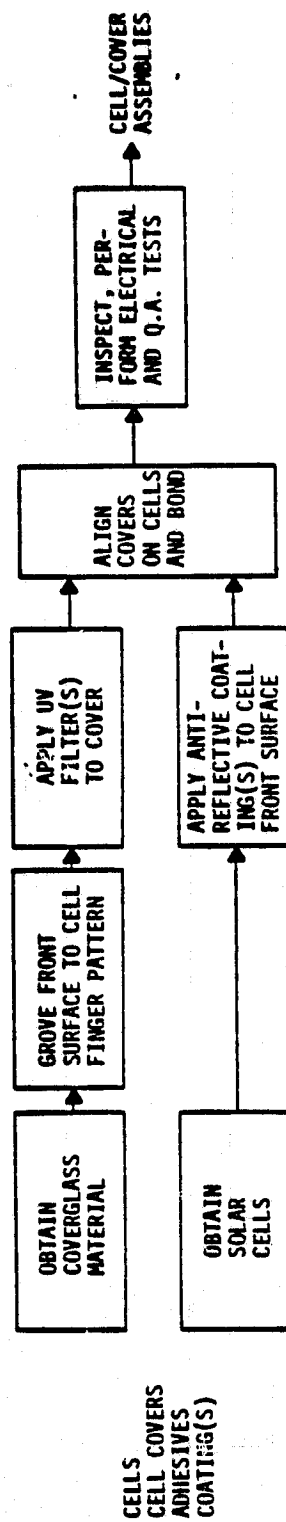


EXHIBIT 3-4. CELL/COVER ASSEMBLY FLOW, PRODUCTION PHASE

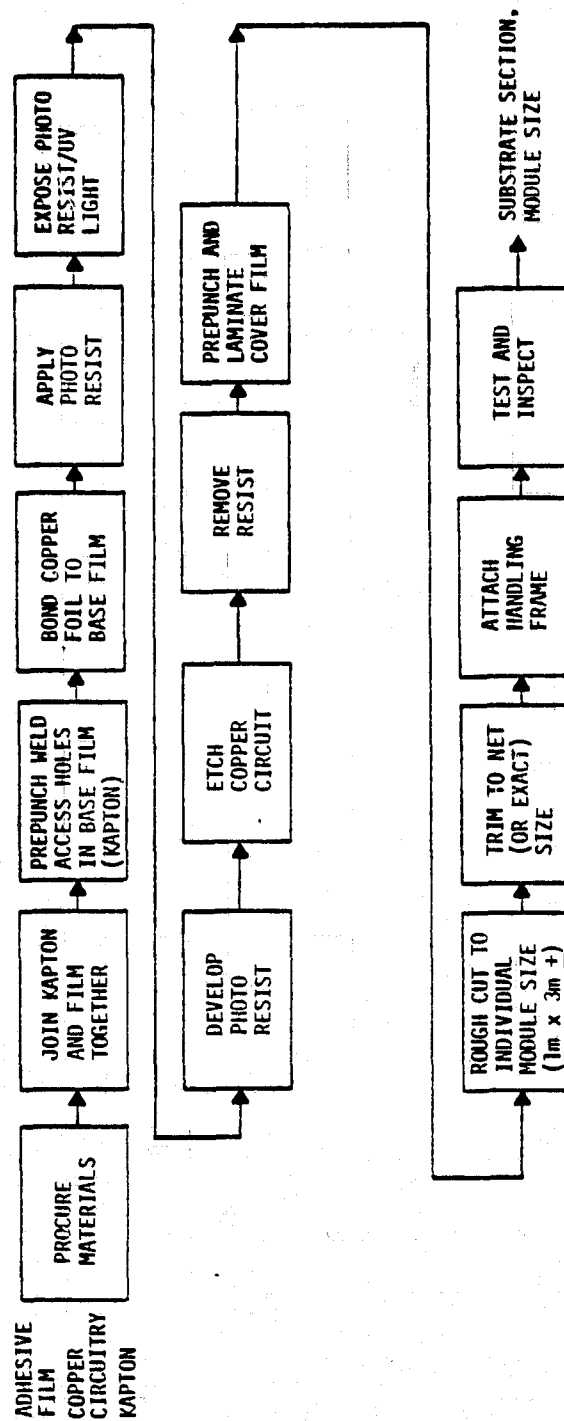


EXHIBIT 3-5. MODULE SUBSTRATE ASSEMBLY FLOW, PRODUCTION PHASE

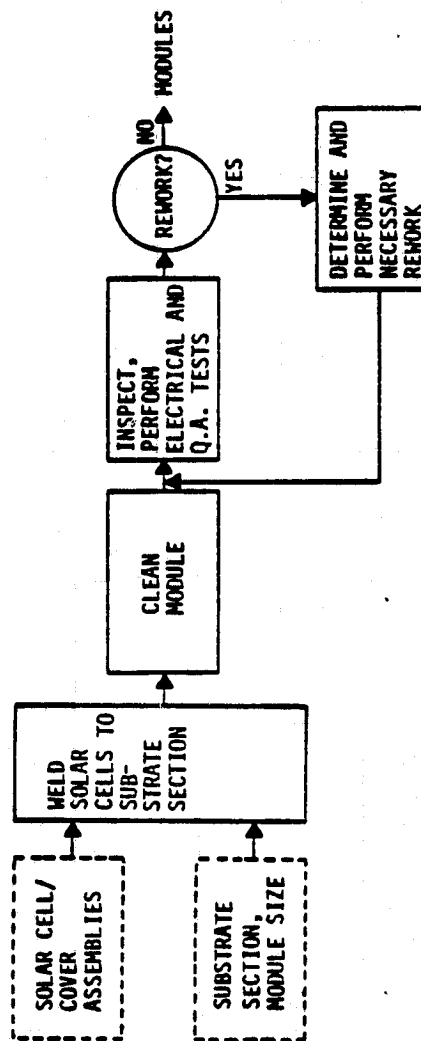
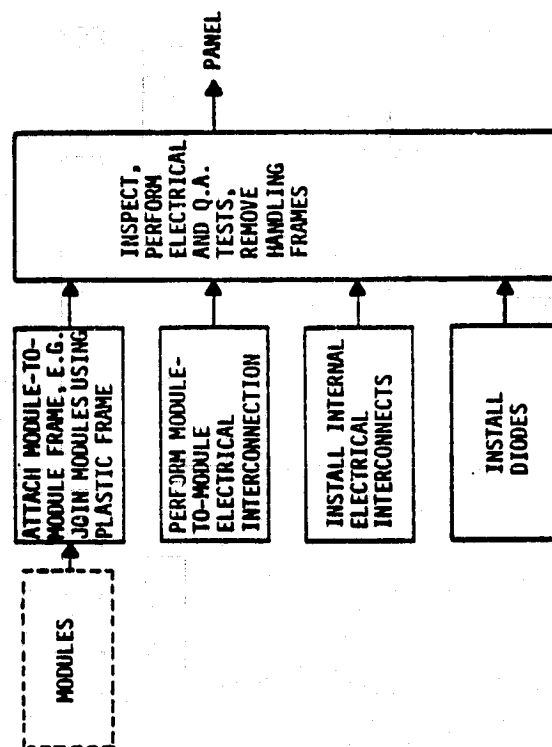


EXHIBIT 3-6. MODULE ASSEMBLY FLOW, PRODUCTION PHASE



MODULE/MODULE FRAME
 MODULE/MODULE ELECTRICAL I.C.
 PANEL INTERNAL ELEC. I.C.
 DIODES

EXHIBIT 3-7. PANEL ASSEMBLY FLOW, PRODUCTION PHASE

PANEL/PANEL HINGE ASSY'S
PANEL/PANEL ELEC. I.C.

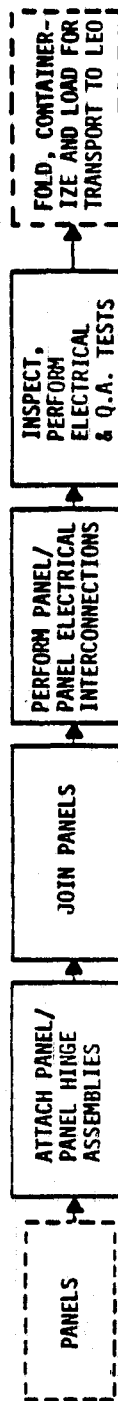


EXHIBIT 3-8. BLANKET ASSEMBLY FLOW, PRODUCTION PHASE

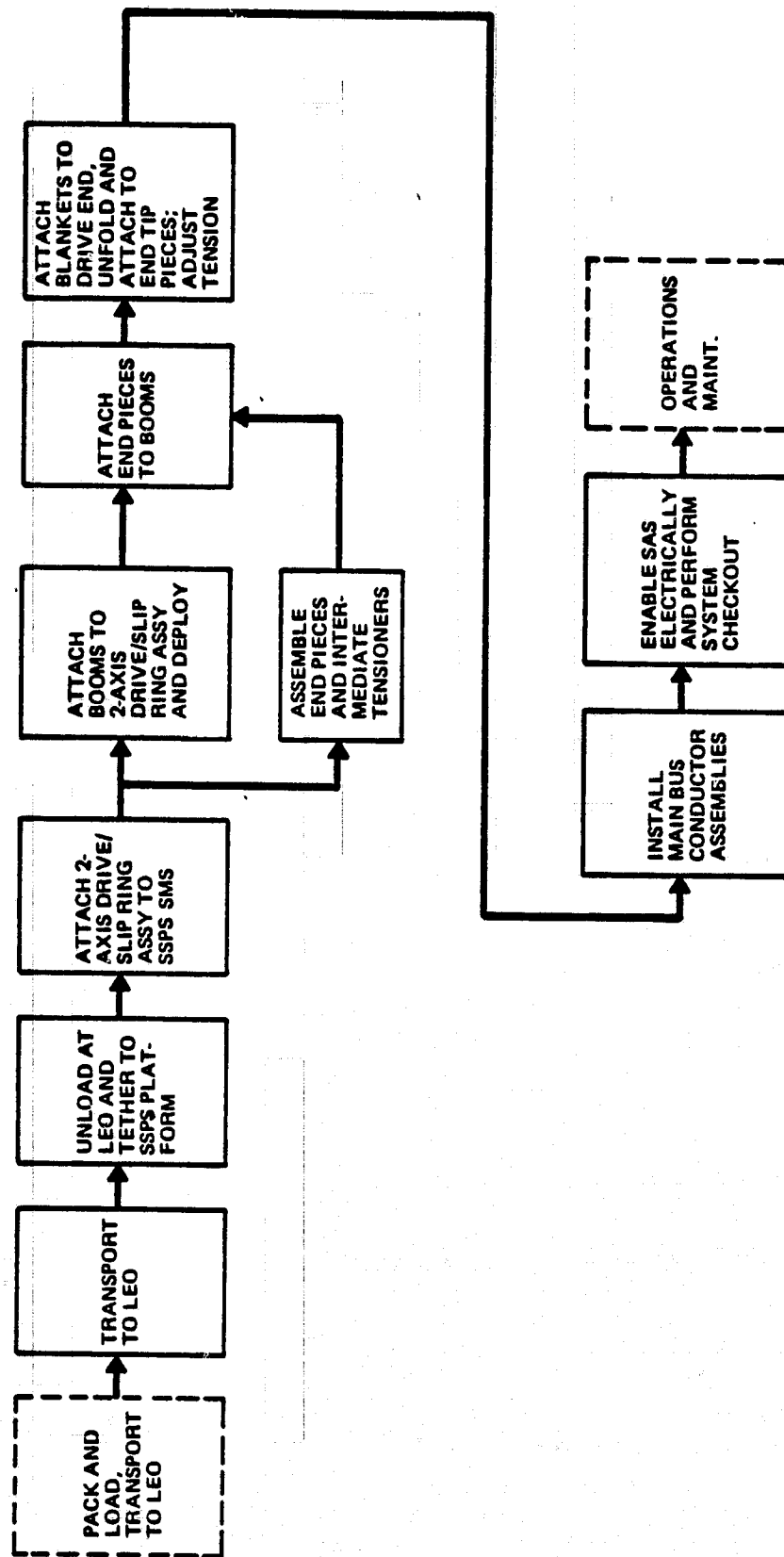


EXHIBIT 3-9. SPACE ASSEMBLY AND CHECKOUT

4.0 TOTAL LIFE CYCLE COST

The purpose of the Solar Array Subsystem Life Cycle Cost Model is to estimate the LCC of the baseline SAS and the different LCC's resulting from variations in the configuration of the SAS.

The basis for the LCCM structure (Exhibit 4-1) is the WBS (Exhibit 1-2) and the functional flow diagrams (Exhibits 3-1, 3-2, and 3-3). The LCCM structure and the functional flows which illustrate in detail the three phases of LCC are compatible with the WBS. The sources for the top level cost relationships (Page B-3) used in the LCCM consist of historical data from the SAS data base and cost and technical data from various vendors.

The Solar Array Subsystem Life Cycle Cost Model consists of three phases: (1) Design, Development, Test and Evaluation; (2) Production and (3) Operations and Maintenance. The direct costs of the baseline are listed in Exhibit 4-3. Refer to Page B-2 for a detailed breakout of cost including direct and indirect costs. The indirect expenses are discussed in Page B-6.

4.1 Design, Development, Test and Evaluation

The cost of the DDT&E phase of life cycle cost is estimated to be 35% of the production phase cost. The DDT&E phase includes the following functions: (1) designing the array and the manufacturing facility and manufacturing the prototype solar array subsystem; (2) designing the development and qualification test requirements and plans and performing development and qualification tests; (3) designing the assembly/integration procedures, designing operations and maintenance procedures, develop training requirements and (4) test and evaluate the solar array subsystem for production decision.

4.2 Total Production Phase Cost

The cost of the production phase is divided into two categories: (1) the manufacturing cost and (2) the cost incurred by NASA to transport the solar array subsystem and astronauts to LEO and the cost of space assembly and check-out.

4.2.1 Total Manufacturing Cost

It is assumed that a prime contractor will manufacture the solar array subsystem using raw stock and off-the-shelf hardware that is presently obtainable.

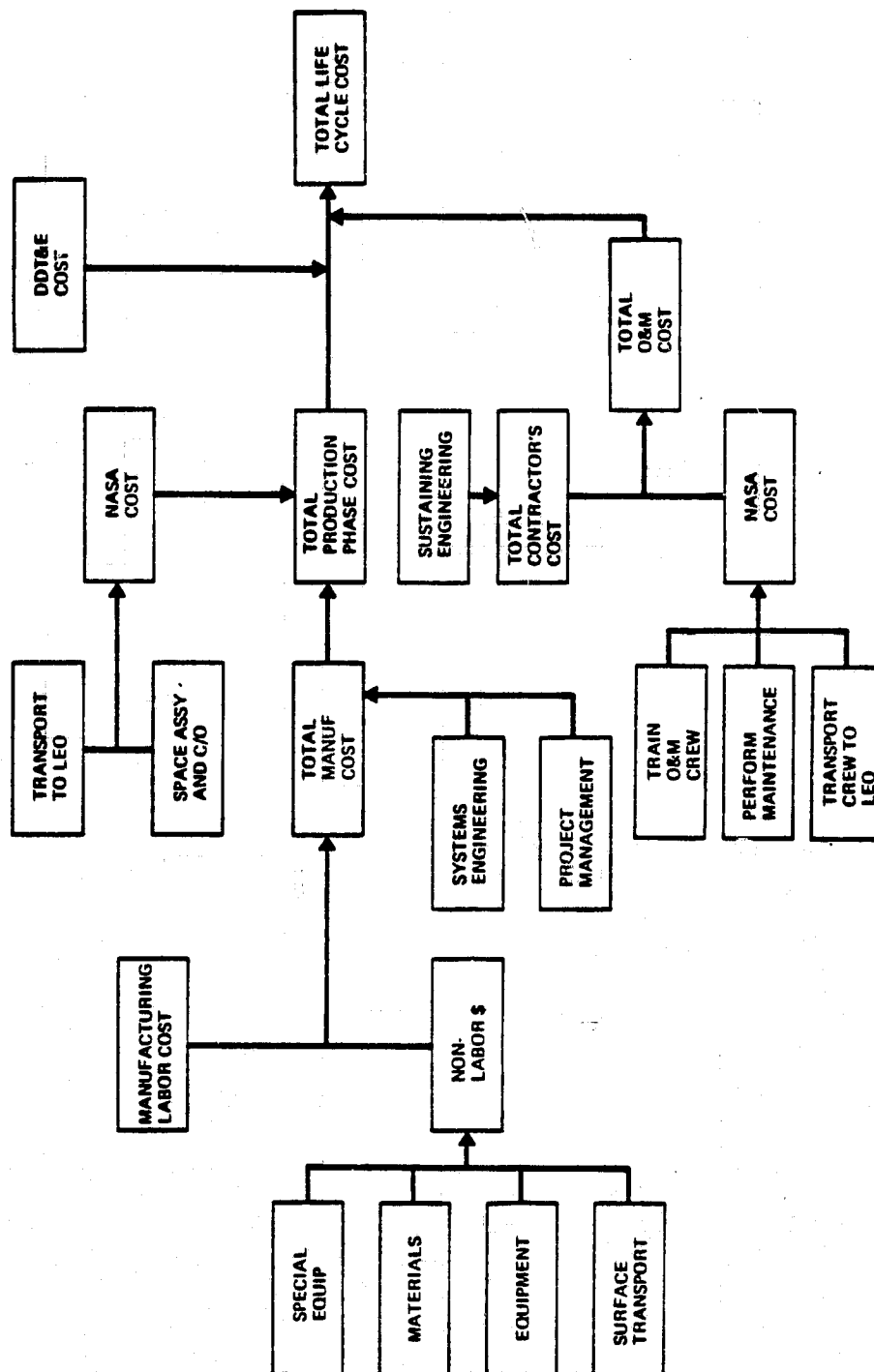


EXHIBIT 4-1. SOLAR ARRAY SUBSYSTEM LIFE CYCLE COST MODEL STRUCTURE

- ALL COSTS IN 1980\$ IN MILLIONS
- STOCK MATERIALS AND COMPONENTS REQUIRED FOR MANUFACTURE OF ARRAY
- DEDICATED FACTORY FACILITY REQUIRED FOR MANUFACTURE OF ARRAY
- COST OF TRANSPORTING SAS BLANKETS AND STRUCTURE TO LEO IS INCLUDED IN PRODUCTION PHASE OF LIFE CYCLE COST
- SHUTTLE FLIGHTS ASSUMED TO BE DEDICATED TO SPACE SERVICES PLATFORM SYSTEM
- OPERATIONS AND MAINTENANCE PHASE OF BASELINE LIFE CYCLE COST COVERS 10 YEAR LIFE OF SAS

EXHIBIT 4-2. GROUND RULES AND ASSUMPTIONS

The total manufacturers cost consists of labor cost, non-labor cost, Project Management and Systems Engineering. The labor and non-labor costs for each WBS item were estimated. These estimates are dependent on the configuration of the SAS and require the inputs described in Exhibit 4-4.

4.2.1.1 Manufacturing Labor Cost

The total manufacturing labor cost consists of the labor cost associated with each manufacturing process.

This cost was estimated based on the number of components required. The number of components determined the number of labor hours. Refer to Exhibit 4-5 for the factors used to determine the labor hours required and the resulting direct labor cost for each manufacturing process.

The labor rate used was \$20/hr. The indirect rates, fringes, overhead and other direct charges, were applied to the direct labor base to obtain the total manufacturing labor cost.

4.2.1.2 Non-Labor Manufacturing Cost

The non-labor manufacturing cost consists of materials, equipment, special equipment and surface transportation. These costs are also dependent on the configuration of the array and require the inputs in Exhibit 4-4.

4.2.1.2.1 Materials

The cost of materials required for each manufacturing process was estimated based on the unit cost and amount required for the process. The unit cost is based on vendor quotes and the amounts required are dependent on the configuration of the SAS. A manufacturing burden to cover the expense of procuring and warehousing materials is applied to the total materials cost. The baseline materials cost for each manufacturing process is listed in Exhibit 4-6.

4.2.1.2.2 Process Equipment

The equipment costs for each manufacturing process for the baseline were estimated based on the production rates required to manufacture the number of components needed for the baseline SAS. Refer to Exhibit 4-7 for a list of the baseline equipment costs.

SAS BASELINE LIFE CYCLE COST
(1980 \$ In Millions)

4.0	TOTAL LIFE CYCLE COST	754.5
4.1	DDT&E	153.9
4.2	TOTAL PRODUCTION PHASE COST:	439.9
4.2.1	Total Manufacturing Cost	376.1
4.2.1.1	Manufacturing Labor Cost	34.0
4.2.1.2	Manufacturing Non-Labor Cost	261.7
4.2.2	NASA Cost:	63.9
4.2.2.1	Shuttle Transportation	63.1
4.2.2.2	Space Assembly and Check-Out	.8
4.3	TOTAL O & M COST:	160.7
4.3.1	Total Contractor's Cost	.9
4.3.2	NASA Cost:	159.8
4.3.2.1	Train O & M Crew	2.5
4.3.2.2	Perform Maintenance	11.0
4.3.2.3	Transport Crew to LEO	146.3

EXHIBIT 4-3

BASELINE INPUTS TO LCCM
(1980 \$)

● Cost of Labor	
ON EARTH	\$ 20/manhour
IN SPACE	250/manhour
● Cost of Materials	
Cell/Cover Assembly	7.75
Module Substrate	142.29/M ²
Module Assembly (welding materials)	740,000
Mechanical and Electrical Interconnects	10,260/panel
Mechanical and Electrical Interconnects	47,000/blanket
● No. of Cell/Cover Assemblies	9,072,000
● No. of modules	2,880
● No. of panels	192
● No. of blankets	4
● Blanket Weight (4)	11,940 kg.
● Structures Weight	7,778 kg.

EXHIBIT 4-4

SAS MANUFACTURING PROCESS FACTORS

AND

BASELINE DIRECT LABOR COSTS

(1980 \$ In Millions)

<u>MANUFACTURING PROCESS</u>	<u>FACTORS</u>	<u>BASELINE LABOR COSTS</u>
Cell/Cover Assembly	4,250 assemblies/hour	2.77
Module Substrate (flexible circuit)	9 m ² /hour	.41
Module Assembly	2.75 modules/hour	3.70
Panel Assembly	.15 panels/hour	4.31
Blanket Assembly	.003 blankets/hour	1.47
Blanket Transport (Fold & containerize)	.003 blankets/hour	.06
Structure Transport (Fold & containerize)	Weight of structure x 1.25 (weight of container) x \$ 2.56	.03
Total Baseline Direct Labor Cost		12.75

EXHIBIT 4-5

SAS BASELINE MATERIALS COST
(1980 \$ In Millions)

<u>PROCESS</u>	<u>COST</u>
Cell/Cover Assemblies	91.40
Module Substrate	1.78
Module Assembly (Welding Materials)	.74
Panel Assembly (Interconnects)	1.97
Blanket Assembly (Interconnects)	.31
Structures	3.07
	<hr/>
TOTAL	99.27

EXHIBIT 4-6

SAS BASELINE PROCESS EQUIPMENT COSTS

(1980 \$ In Millions)

<u>PROCESS</u>	<u>COST</u>
Cell/Cover Assembly	6.17
Module Substrate (flexible circuit)	9.83
Module Assembly	60.51
Panel Assembly	37.12
Blanket Assembly	25.71
Blanket Transport (Fold & containerize)	1.76
Structure Transport (Fold & containerize)	.44
TOTAL	141.54

EXHIBIT 4-7

4.2.1.2.3 Special Equipment

The special equipment consists of containers for packaging the SAS blankets and structures for shipment to the launch site and to LEO aboard the Space Shuttle.

4.2.1.2.4 Surface Transportation

Surface transportation costs consist of the cost of transporting the SAS blankets and structures to the launch site from the manufacturing facility. It was assumed the manufacturing facility would be located on the West Coast and the launch site would be Kennedy Space Center. The cost is dependent on the combined weight of the structure, blankets and the containers in which they are packaged.

4.2.2 NASA Cost

The NASA incurred cost portion of the total production phase cost consists of: (1) the cost of transporting the SAS blankets, structures and the SA & CO astronaut crew to LEO aboard the Space Shuttle and (2) the cost of the assembly and check-out in space.

4.2.2.1 Transportation to LEO

It is assumed that the SAS will be transported to LEO on Space Shuttle flights dedicated to the SSPS. Therefore, the transportation costs for the SAS are dependent on the weight of the SAS. The cost of transporting the astronauts and the equipment used for assembly and check-out is estimated to be 1/7 or 14% of the cost of one dedicated flight because the SAS is one of seven subsystems of the SSPS.

4.2.2.2 Space Assembly and Checkout

Space assembly and check-out includes the cost of the astronaut crew's labor to assemble and check-out the SAS in space and the cost of the equipment used. The labor cost is a function of the weight of the SAS.

4.2.3 Project Management

The cost of Project Management is estimated to be 5.8% of the sum of the manufacturing labor and non-labor costs. Project Management includes planning,

organizing, directing, coordinating and controlling the project to ensure that overall project objectives are accomplished.

4.2.4 Systems Engineering

The cost of the System Engineering is estimated to be 4.8% of the sum of the manufacturing labor and non-labor costs. This function includes the application of scientific engineering efforts to: (1) transform an operational need into a description of system performance parameters and a system configuration; (2) integrate related technical parameters and assure compatibility of all physical, functional and project interfaces in a manner which optimizes total system definition and design; and (3) integrate the efforts of all engineering disciplines and specialties into the total engineering effort.

4.3 Total Operations and Maintenance Phase Cost

The Operations and Maintenance Phase of the life cycle covers the ten year life span of the SAS. There are two categories of cost in this phase: (1) a contractor's cost for the sustaining engineering's function and (2) a cost incurred by NASA to train the operations and maintenance crew, transport the crew to LEO and perform maintenance on the SAS over a ten-year period.

4.3.1 Total Contractor's Cost

It is assumed that a contractor housed at the launch site will provide sustaining engineering for the SAS over a ten-year period. It is assumed that one engineer working 2,040 hours a year at \$20 an hour for ten years would constitute the labor cost. The total contractor cost for sustaining engineering is obtained by applying the fringes, overhead and other direct cost rates to the direct labor base. A general and administrative rate is also included in the total contractor's cost.

4.3.2 NASA Incurred Cost

The cost incurred by NASA in the O&M phase is the sum of the cost of training the crew, transporting them to the SSPS in LEO and performing the maintenance over a ten-year period.

4.3.2.1 Train O & M Crew

It is estimated that it will be necessary to train one astronaut crewman

per year for ten years. The cost for this training is estimated to be \$250,000 per year per crewman.

4.3.2.2 Perform Maintenance

The crew that performs the maintenance on the array is divided into two groups. One crew remains on the SSPS to perform scheduled maintenance. The crew works for three month periods on the space platform and is sent back to earth to be replaced by another crew. The unscheduled maintenance is performed by an earth based crew that makes a number of unscheduled trips to the SSPS per year.

4.3.2.3 Transport Crew to LEO

Four trips a year for ten years are required for the crew that is housed on the SSPS. The cost is \$250K per trip. The unscheduled maintenance crew requires 1.75 trips per year @ \$100K per unscheduled maintenance.

4.4 Summary

The LCCM provides a means of estimating the LCC of a SAS. LCC can be determined as various technology parameters of the baseline are varied during Task III. Specific technology parameters versus LCC were quantified based on the Mission scenario described in paragraph 2.1.

These were:

- Solar cell thickness/LCC
- Cover thickness/LCC
- Cell efficiency/LCC
- Cell degradation/LCC
- Cover degradation/LCC
- Cell and cover assembly costs/LCC
- Temperature (blanket assembly)/LCC
- Voltage (line)/LCC

In addition to the technology parameters listed above, two maintenance-related parameters versus LCC were quantified.

These were:

- Years between overhaul/LCC
- Mean time between failure/LCC

The O&M portion of the baseline mission scenario was altered in each case to accommodate the change in maintenance-related parameters. The specific changes in configuration and the resulting LCC's will be discussed in detail in Section 5.0.

5.0 SOLAR ARRAY PERFORMANCE AND COST MODEL

5.1 Basic Concept

The Solar Array Performance and Cost Model (SAPCM) was developed to a level of detail required to support the cost/technology analyses of Task III. The modeling approach, generally, was to

- define the solar cell, cover, substrate and cell interconnect circuitry (module cross section)
- determine the value of the solar array factors which affect performance and apply to the BOL cell/cover assembly to determine the EOL per cell array performance.
- determine number of cell/cover assemblies required for baseline orbit and load power/energy requirements
- determine total array area, dimensions and structural requirements (Array Configuration)
- determine array weight breakdown and totals
- determine life cycle cost.

5.2 Description of Model

A block diagram of the SAPCM is shown in Exhibit 5-1. A discussion of the various blocks or functions is contained in the following paragraphs. To facilitate discussion of the block diagram, the baseline SAS is used as an example of exercising the model.

5.2.1 Solar Array Performance Parameters

The heart of the SAPCM consists of various solar cell performance parameters which are used to determine the equivalent End-of-Life (EOL) per cell performance. The individual factors which are depicted in Exhibit 5-2 are as follows:

- Cover Factors ($F_C = F_G + F_T$)
 1. Glassing, F_G
 2. Cover Degradation, F_T

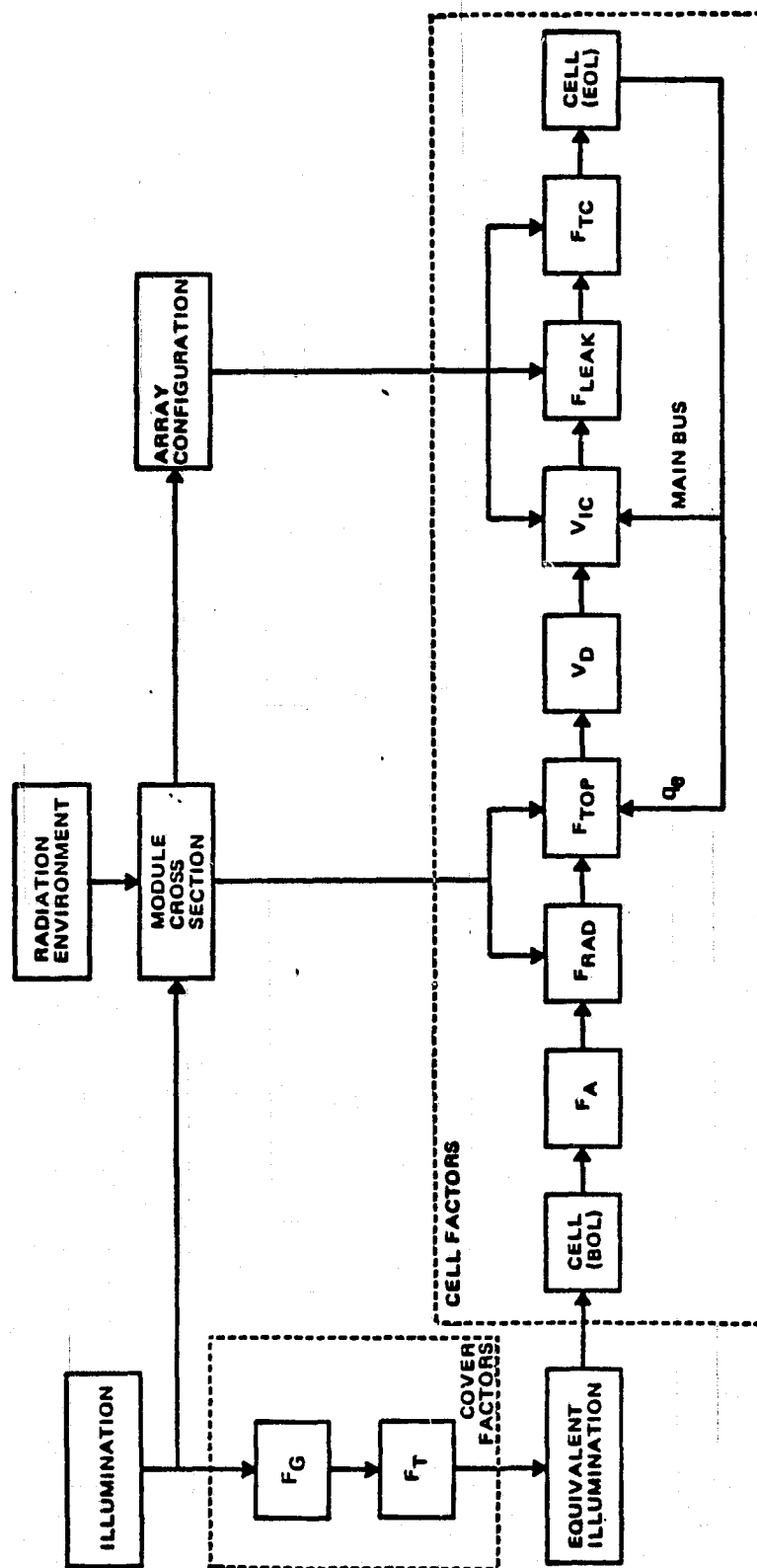


EXHIBIT 5-2 ARRAY PERFORMANCE PARAMETERS

● Cell Factors

1. Assembly, F_A
2. Cell Degradation, F_{RAD}
3. Temperature Derating, F_{TOP}
4. Diode, V_D
5. Solar Cell IC, V_{sc}
6. Module/Module IC, V_{mm}
7. Panel/Panel IC, V_{pp}
8. Main Bus Conductors, V_{mb}
9. Slip Ring Conductors, V_{sr}
10. High Voltage Leakage Loss, F_{leak}
11. Temperature Cycling, F_{tc}

} V_{IC}

The basic interrelationship of the various parameters can be expressed as follows:

$$EOL P_{mp} (W/m^2) = \left[(\eta_{BOL} \times \prod_{i=1}^n F_{P_i}) \times (S' \times \prod_{j=1}^2 F_{P_j}) \times PF \right] \times A_s$$

Where P_{mp} = per cell max power

F_{P_i} = cell performance factors

F_{P_j} = cover performance factors

S' = effective illumination

η_{BOL} = cell BOL efficiency

PF = per cell packing factor

A_s = per cell array area

As can be seen in Exhibit 5-2, feedback loops which affect the array average temperature and the main bus configuration lead to iterations in order to arrive at the final result. The above relationship is used to determine the average minimum power of the array at EOL for a unit area of $1 m^2$, which is further scaled down on a per-cell module cross-section basis. The equivalent EOL

per-cell power is then used to size the array and thus determine the array configuration. The per cell voltage is similarly calculated and used for sizing.

The individual factors are discussed in subsequent paragraphs; however, for comparison with Exhibit 5-1, cell factors are further categorized as follows:

- Radiation Degradation
- Temperature Derating
- Array Loss Factors
 - Assembly
 - Distribution (Diode, V_{IC})
 - Leakage
 - Temperature Cycling

5.2.1.1 Module Assembly Cross Section

The module assembly is the solar array building block. For the SAS baseline, the module assembly cross section (Exhibit 5-3) consists of the following:

- Solar Cell
0.022 x 4.000 cm, wraparound contact, 8 mil
silicon, 2 ohm-cm AMO base resistivity, 12.2%
unglassed efficiency, 28°C ambient, $Ta_{2}O_{5}$ anti-
reflective coating
- Cell Cover
2.022 x 4.000 cm, 6 mil fused silica, uv filter,
300 μ m filter cut-on
- Cover Adhesive
2 mil DC-93-500
- Substrate
Laminated printed circuit, 33% area, 1 mil copper rolled
annealed interconnect. Insulation is two sheets of 0.5 mil
kapton/0.5 mil high-temperature polyester adhesive.

5.2.1.2 Array Illumination

An illumination summary for the SAS baseline is shown below. The orbit maximums and minimums call for minimum and maximum distances from the sun

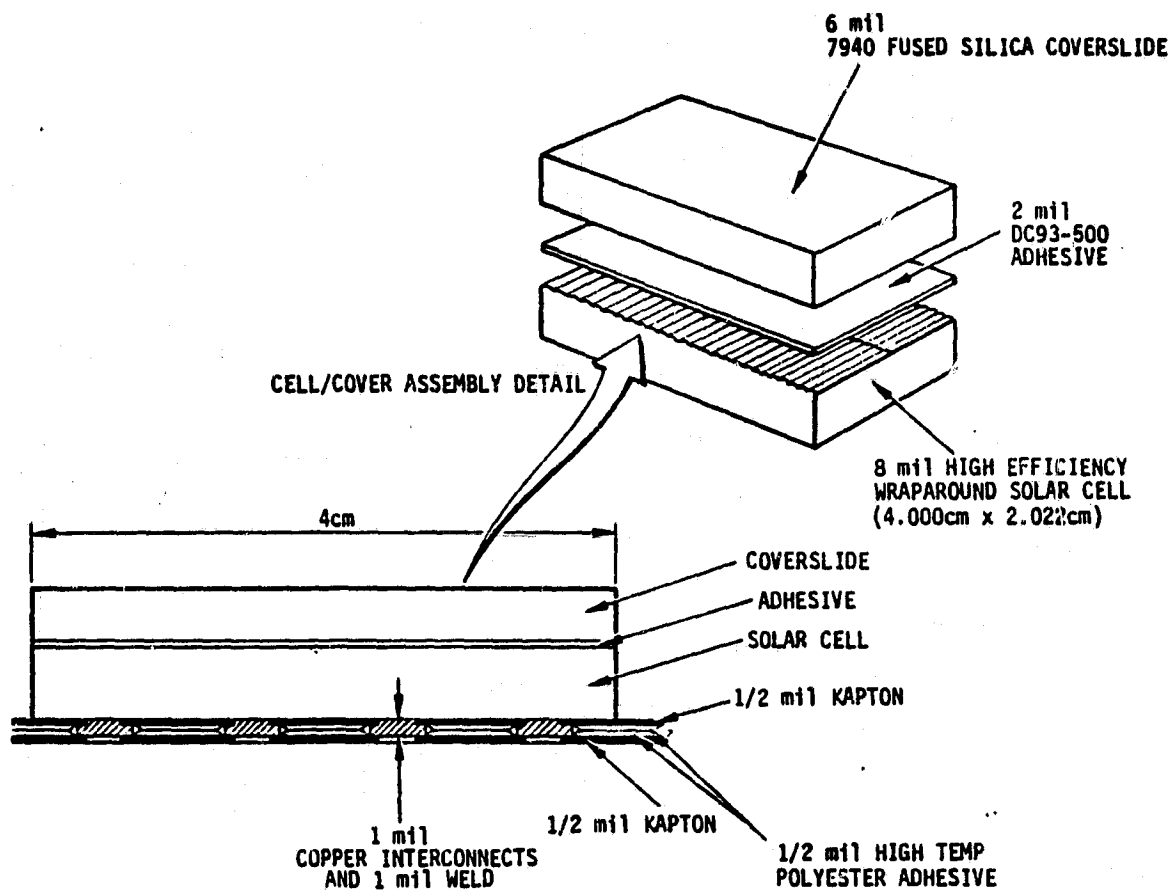


EXHIBIT 5-3. MODULE CROSS SECTION

respectively. The maximum albedo contribution is 36% of the solar illumination. The values for total orbit averages were obtained by averaging the calculated values of solar illumination plus albedo for each minute of illumination in orbit. The baseline total effective averages include the effects of cover glassing and cover degradation.

<u>ILLUMINATION</u>	<u>MAX</u>	<u>AVG</u>	<u>MIN</u>
Solar	1399	1353	1309
Albedo (36%)	504	487	471
Total Orbit Avg.	1478	1430	1383
Cover Glassing			
Factor	1.017	1.017	1.017
Cover Degradation			
Factor	.870	.870	.870
Baseline Total			
Effective Avg.	1308	1265	1224

5.2.1.2.1 Cover Glassing

The cover glassing factor is a measure of the optical impedance matching between the cell cover and the solar cell. Not only does the cover glass material and cover adhesive determine this factor, but also the antireflective coating applied to the solar cell itself. For the SAS baseline, the cover glassing factor is 1.017.

5.2.1.2.2 Cover Degradation

The cover degradation factor is a measure of how the transmissibility of the cover (and cover adhesive) degrades over the lifetime of the array. This effect is caused by a cumulation of the following effects:

- ultraviolet radiation dose
- particulate radiation dose
- micrometeorites

For the SAS baseline, the cover degradation factor is .870.

5.2.1.3 BOL Cell Performance

The assumed BOL Cell Performance for the SAS Baseline is 12.2% unglassed efficiency and $V_{mp} = .479V$. ($S' = 1353 \text{ w/m}^2 @ 28^\circ\text{C}$).

5.2.1.4 Physical Parameters

This function consists of calculating the parameters indicated in Exhibit 5-4. These parameters are also used as inputs to radiation shielding, thermal mass, main bus calculations as described in subsequent paragraphs. The SAS baseline parameters are summarized in Exhibit 5-4.

5.2.1.5 Radiation Environment

The radiation degradation factor is a measure of the degradation in solar cell output due to high-energy charged particles, e.g., electrons and protons in the orbital environment. The degradation involved is a cumulative effect measured over the lifetime of the array in orbit. The amount of degradation is determined by the number of particles which have sufficient energy to penetrate the solar cell and cause permanent damage. Hence, the primary function of the solar cell cover is to reduce the quantity of particles which penetrate the solar cell. The substrate materials also assist in reducing radiation degradation. The methodology for determining this factor is summarized in the next three paragraphs.

5.2.1.5.1 Radiation Shielding

First, the effective radiation shielding provided by the various solar array module materials is determined. The results of this analysis for the baseline module are summarized in Exhibit 5-5. The analysis was accomplished by converting all materials to equivalent fused silica density shielding.

5.2.1.5.2 Radiation Flux

Next, the protection provided by the radiation shielding is determined. To accomplish this, Exhibit 5-6 was used to determine the equivalent fluence summary for 444 KM, 56° inclination. This table is based upon historical data for different thickness of fused silica in a radiation environment similar to that anticipated for the baseline solar array described herein. The output of this table is the cumulative fluence of charged particles which will have sufficient energy to cause degradation of the solar cell over the array lifetime. For the SAS baseline,

$$\text{Cell Area} = L \times W = A_c = 4.000 \text{ cm} \times 2.022 \text{ cm} = 8.088 \text{ cm}^2$$

$$\text{Substrate Area} = (L + d_L) \times (W + d_W) = A_s = 4.000 \text{ cm} + 0.130 \text{ cm} \times 2.022 \text{ cm} + 0.130 \text{ cm} = 8.888 \text{ cm}^2 \text{ (per cell)}$$

$$\text{Packing Factor} = A_c \div A_s = PF = 8.088 \text{ cm}^2 \div 8.888 \text{ cm}^2 = .910$$

Cell/Cover Assembly	T (mil)	D (kg/m ³)	M (kg/m ²)	A (cm ²)	W (g)
Cover	6	2200	.3353	8.088	.2712
Adhesive	2	1080	.0549	8.038	.0444
Cell	8	2600	.5283	8.088	.4273
TOTALS	16	2260	.9185	8.088	.7429

Substrate Assembly	T (mil)	D (kg/m ³)	M (kg/m ²)	A (cm ²)	W (g)
Kapton	.5	1400	.0178	8.888	.0158
Adhesive	.5	1420	.0180	8.888	.0160
Copper	1	8890 + 3	.0753	8.388	.0669
Adhesive	.5	1420	.0180	8.888	.0160
Kapton	.5	1400	.0178	8.888	.0158
TOTALS	3	1927	.1468	8.888	.1305

Module Assembly	T (mil)	D (kg/m ³)	M (kg/m ²)	A (cm ²)	W (g)
Cell/Cover Assembly	16	2057	.8358	(1) 8.888	.7429
Substrate Assembly	3	1927	.1468	8.888	.1305
TOTALS	19	(1) 2036	(1) .9827	8.888	.8734

(1) Includes packing factor (PF)

EXHIBIT 5-4. PHYSICAL PARAMETERS

FRONT

MATERIAL	MATERIAL THICKNESS (mil)	MATERIAL DENSITY (Kg/m ³)	EQUIVALENT THICKNESS (mil)
Cover	6	2200	6.00
Adhesive	2	1080	.98
TOTALS	8	1920	6.98

BACK

MATERIAL	MATERIAL THICKNESS (mil)	MATERIAL DENSITY (Kg/m ³)	EQUIVALENT THICKNESS (mil)
Cell	8	2600 x .375	3.55
Kapton	.5	1400	.32
Adhesive	.5	1420	.32
Copper	1	8890 ÷ 3	1.35
Adhesive	.5	1420	.32
Kapton	.5	1400	.32
TOTALS	11	1236	6.18

EXHIBIT 5-5. RADIATION SHIELDING

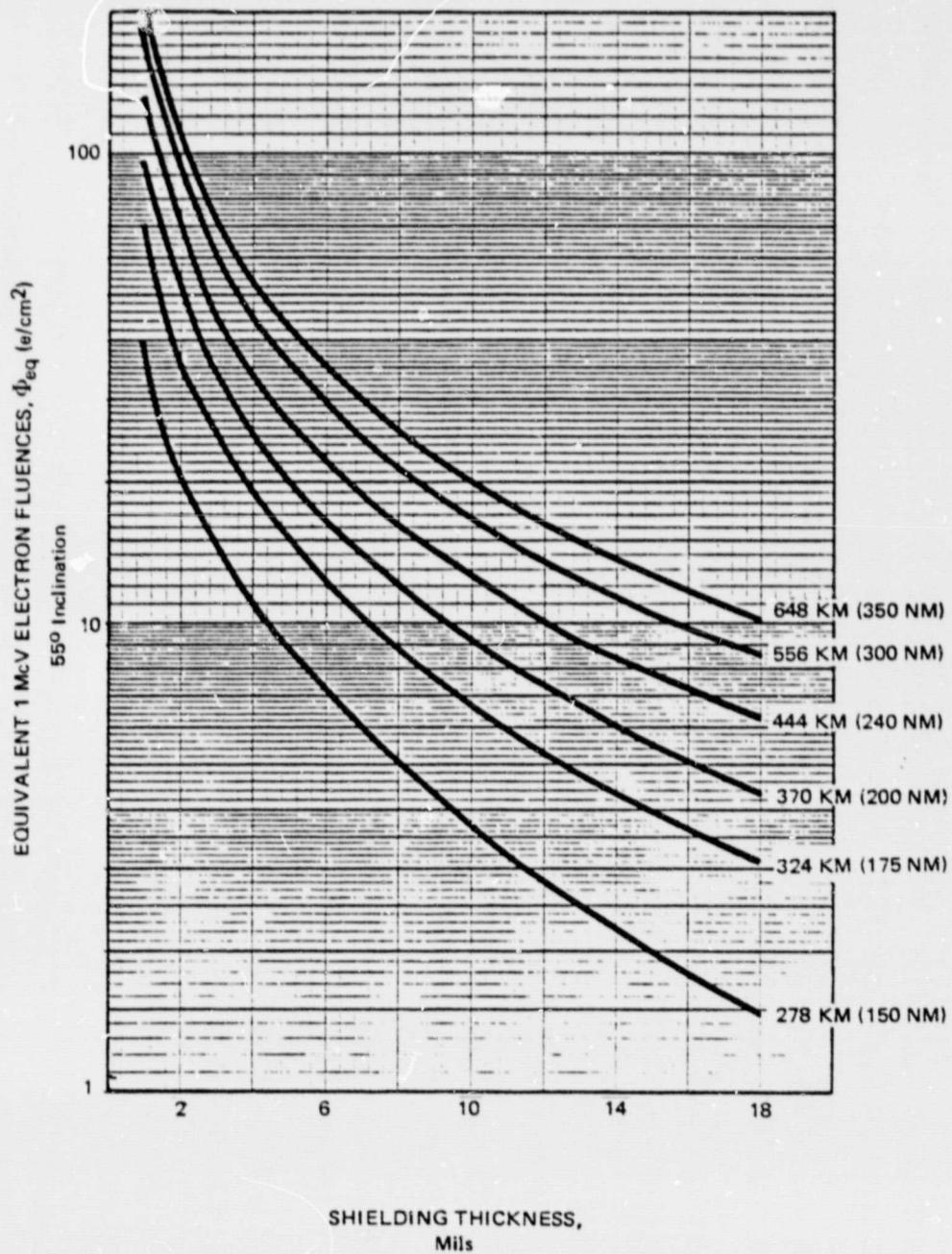


EXHIBIT 5-6. RADIATION FLUX

the total flux for a 10-year period, was 40.89×10^{13} . This consisted of 19.01×10^{13} for the front shielding and 21.88×10^{13} for the back shielding respectively.

5.2.1.5.3 Radiation Degradation

Finally, the predicted solar cell degradation caused by particles with sufficient energy to penetrate the radiation shielding and cause solar cell damage is determined. To accomplish this, the data in Exhibit 5-7 is used. Based upon the equivalent fluence, a predicted degradation is determined. For the SAS baseline, the power degradation factor is .854 for an array life of 10 years, while the voltage factor is .968.

5.2.1.6 Array Temperature

The temperature derating factor is a measure of the effect of the operating temperature upon cell performance. The methodology for determining this factor is summarized in the next three paragraphs.

5.2.1.6.1 Thermal Mass

This function consists of calculating the parameters indicated in Exhibit 5-8. Thermal mass is in turn used as a parameter in the temperature calculations described in paragraph 5.2.1.6.3. The thermal mass for the SAS baseline is also plotted as a function of temperature in Exhibit 5-8.

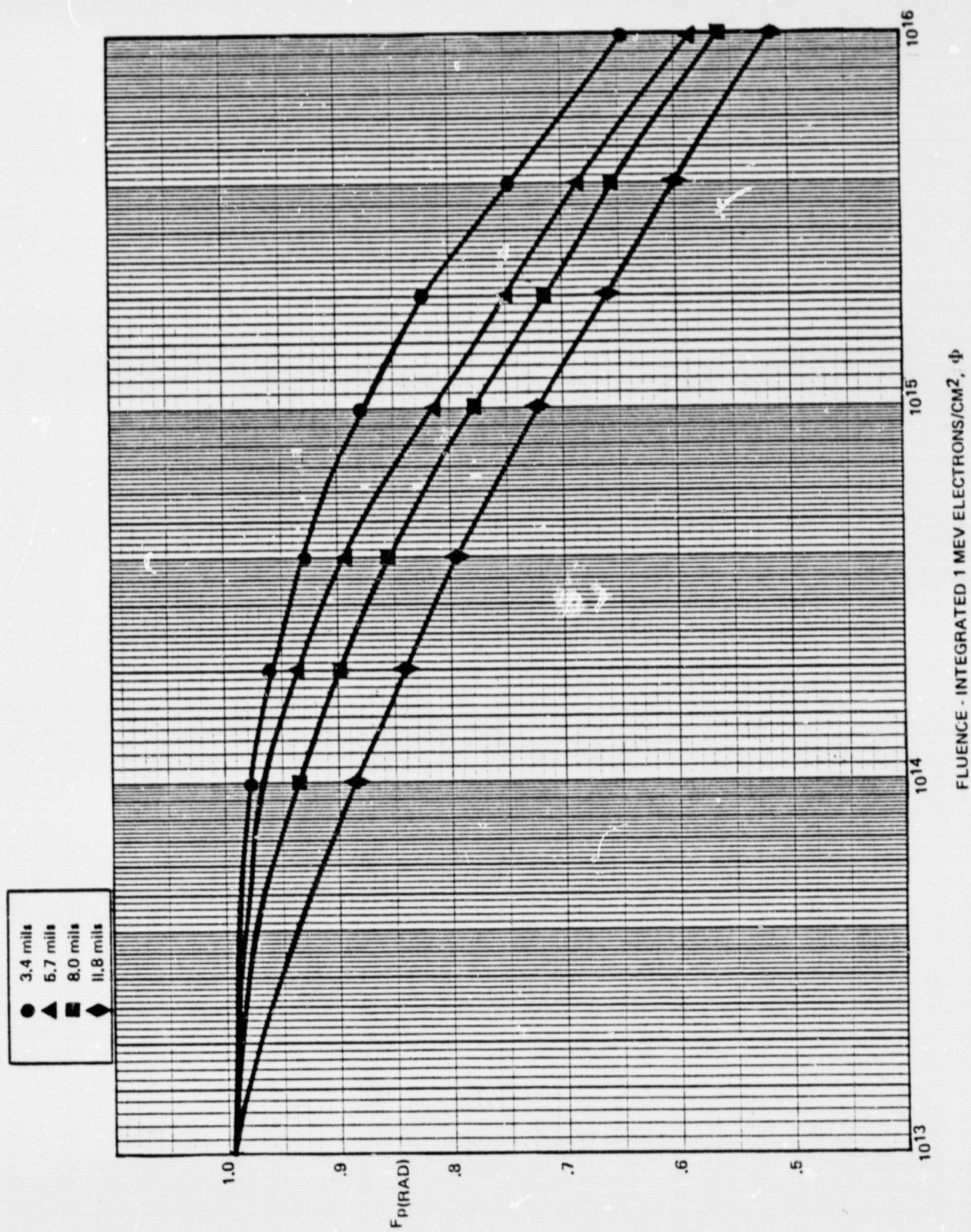
5.2.1.6.2 Thermal Properties

This function consists of calculating the parameters indicated in Exhibit 5-9. These properties are in turn used in the temperature calculations described in the subsequent paragraph. The thermal properties for the SAS baseline are summarized in Exhibit 5-9.

5.2.1.6.3 Temperature Derating

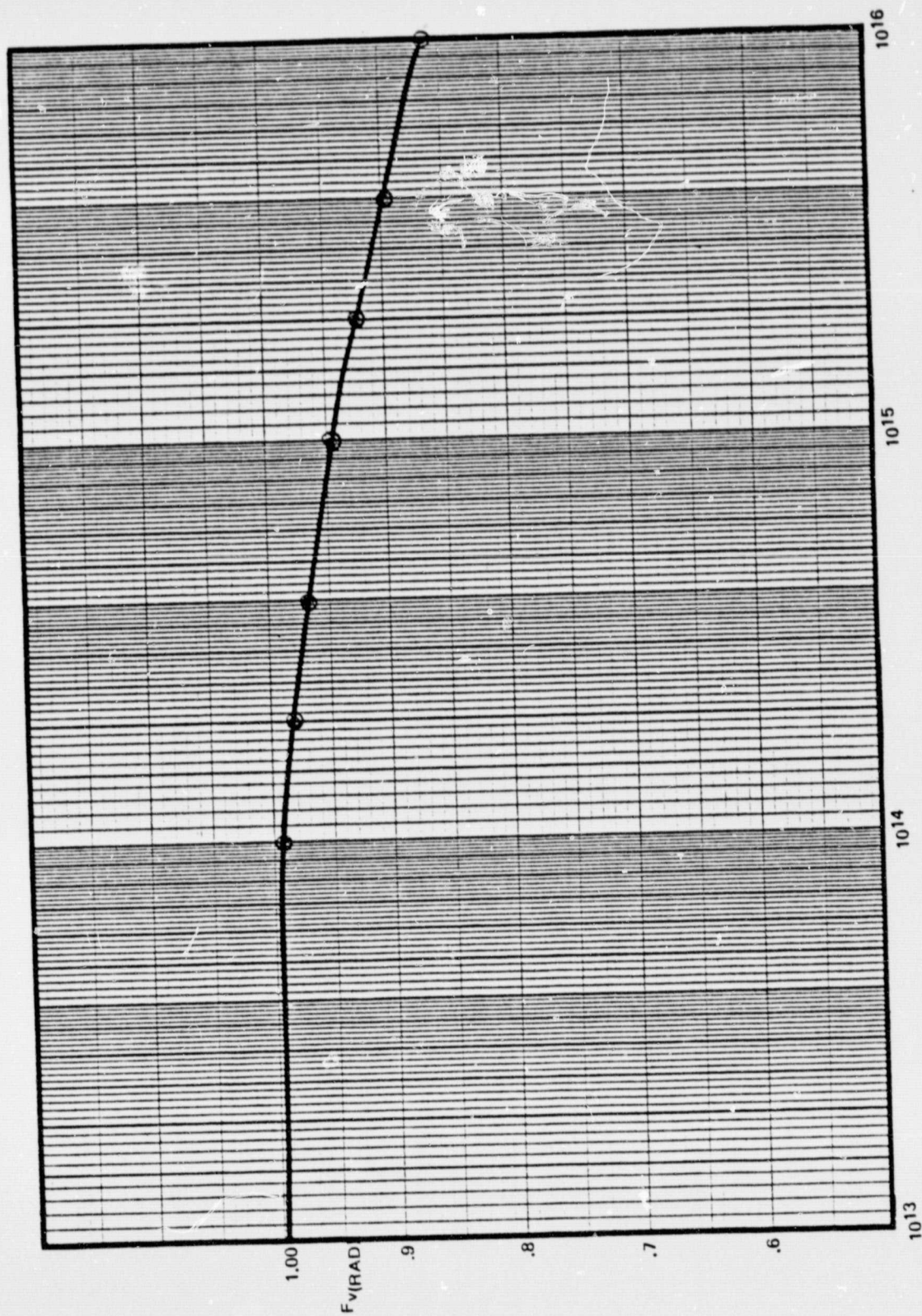
The most complex function of the SAPCM is determining the cell temperature derating factor. Using the array thermal mass profile and the thermal properties discussed in the preceding paragraphs, this factor is calculated using the following procedure:

- Determine array temperature vs time profile during period of minimum solar illumination (including effects of albedo, earth radiation, and heat from the space platform).



FLUENCE - INTEGRATED 1 MEV ELECTRONS/CM², Φ

EXHIBIT 5-7. RADIATION DEGRADATION (POWER)



FLUENCE - INTEGRATED 1 MEV ELECTRONS/CM², Φ

EXHIBIT 5-7. RADIATION DEGRADATION (VOLTAGE) (Continued)

SOLAR ARRAY

THERMAL MASS

BASELINE MATERIAL	ARRAY MASS	-100°C		-75°C		-50°C		-25°C		-0°C		25°C		50°C		75°C		100°C	
		Cp	mCp	Cp	mCp	Cp	mCp	Cp	mCp	Cp	mCp	Cp	mCp	Cp	mCp	Cp	mCp	Cp	mCp
Cover	(1) .3051	475	145	510	156	575	175	625	191	675	206	720	220	765	233	800	244	850	259
Adhesive	(1) .0500	660	33	725	36	795	40	865	43	910	46	945	47	985	49	1000	50	1015	51
Cell	(1) .4808	500	240	560	269	615	296	650	313	700	337	720	346	725	349	735	353	750	361
Kapton	.0178	725	13	800	14	875	16	950	17	1000	18	1040	19	1085	19	1100	20	1115	20
Adhesive	.0180	725	13	800	14	875	16	950	17	1000	18	1040	19	1085	20	1100	20	1115	20
Copolymer	.0753	315	24	320	24	330	25	335	25	350	26	380	29	415	31	440	33	495	37
Adhesive	.0180	725	13	800	14	875	16	950	17	1000	18	1040	19	1085	20	1100	20	1115	20
Kapton	.0178	725	13	800	14	875	16	950	17	1000	18	1040	19	1085	19	1100	20	1115	20
TOTALS		494		541		600		640		687		718		740		760		788	

(1) Includes PF = .91

EXHIBIT 5-8

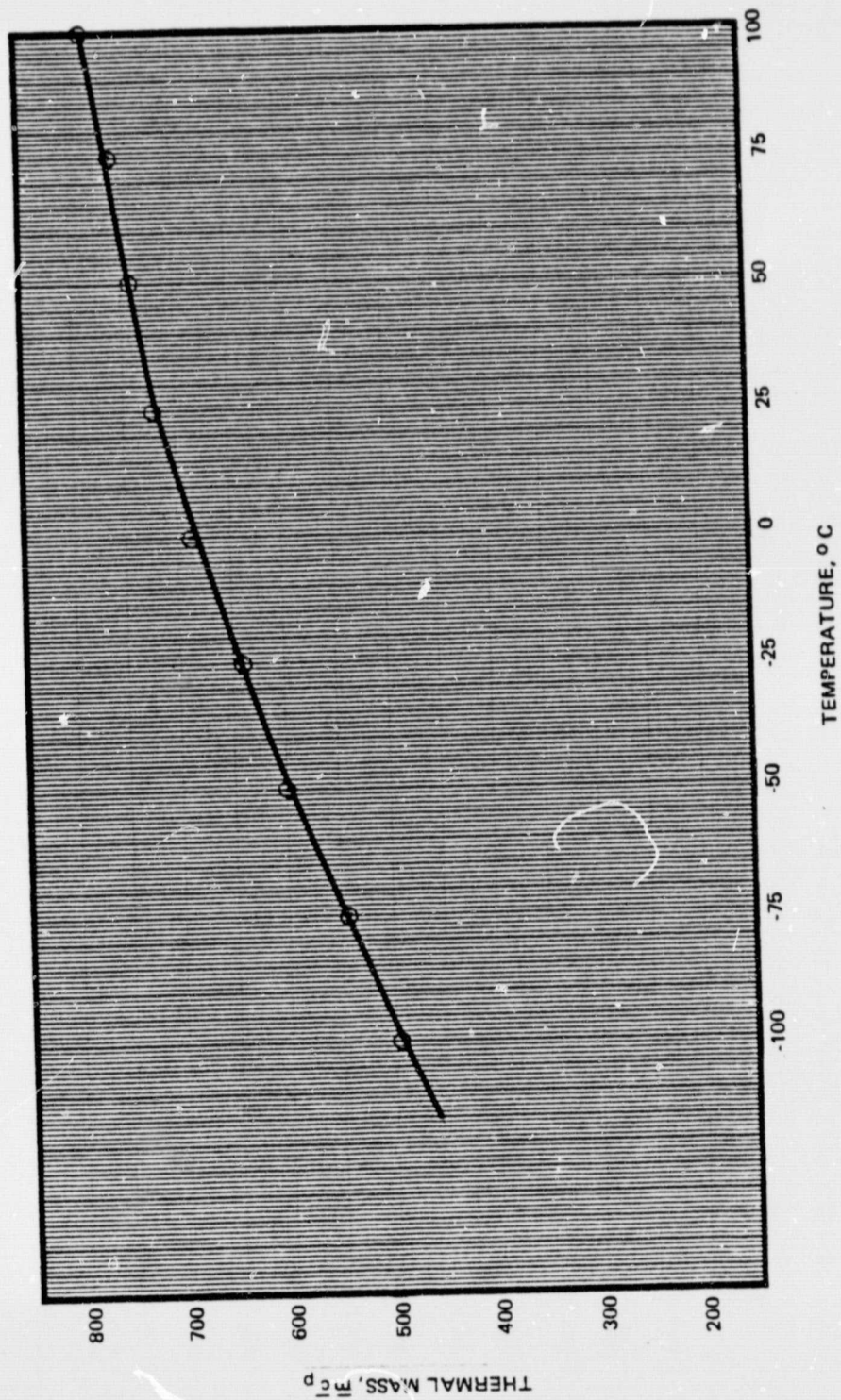


EXHIBIT 5-8. SOLAR ARRAY THERMAL MASS (Continued)

$$\bar{\alpha}_F = \alpha_{\text{cover}} \times PF + \alpha_{\text{substrate}} \times (1-PF) = .780 \times .910 + .450 \times .090 = .750$$

$$q_E = F_p \times \text{EOL loss factor} \times \eta_{\text{BOL}} = .910 \times .45 \times .122 = .050$$

$$\alpha_B = .450 \quad \alpha_{\text{SF}} = \bar{\alpha}_F - q_E = .750 - .050 = .700$$

$$F = \epsilon_{\text{cover}} \times F_p + \epsilon_{\text{substrate}} \times (1-F_p) = .820 \times .910 + .800 \times .090 = .818$$

$$\epsilon_B = \epsilon_{\text{substrate}} \times \text{adj factor} = \epsilon_B \quad .800 \times .75 = .600$$

EXHIBIT 5-9. THERMAL PROPERTIES

$$q_{AL}(F) = \bar{\alpha}_{SF} \times .36 \times S' \times \cos \Gamma_2 \quad (\text{Albedo})$$

$$q_{AL}(B) = \alpha_B \times .36 \times S' \times \cos \Gamma_2 = .450 \times .36 \times S^1 \times \cos \Gamma_2$$

$$q_{ER}(F) = \bar{\alpha}_F \times 208.2 \times \cos \Gamma_3 = .750 \times 208.2 \times \cos \Gamma_3 = 156.2 \times \cos \Gamma_3$$

$$q_{ER}(B) = \alpha_B \times 208.2 \times \cos \Gamma_3 = .450 \times 208.2 \times \cos \Gamma_3 = 93.7 \times \cos \Gamma_3$$

$$q_{SP} = \epsilon_B \times (\quad_{SP} \times \cos \Gamma_4 \times \cos \Gamma_4) \times (\sigma) \times (.04) = .600 \times (.050 \times .7071 \times .7071) \times (5.6697 \times 10^{-8}) \times$$

$$(50 \quad_{273})^4 = 9.3$$

$$\epsilon_{\sigma} = (\epsilon_F + \epsilon_B) \times (1 + \alpha_{SP} \times \cos \Gamma_4 \times \cos \Gamma_4) \times (\sigma) = (.818 + .600) \times (1 + .050 \times .7071 \times .7071) \times$$

$$(5.6697 \times 10^{-8}) = 8.24 \times 10^{-8}$$

- Determine average array temperature during same period.
- Determine array illumination vs time profile during period of minimum solar illumination (including albedo = 36%).
- Determine average illumination during same period.
- Determine effect of cell cover glassing and degradation factors upon effective illumination "seen" by solar cell.
- Determine power derating factor by extrapolating the data summarized in Exhibit 5-10, using the average temperature and effective illumination determined above.
- Repeat same procedure for voltage derating factor for period of maximum solar illumination, using average temperature only.

(See Appendix C for the effect of various parameters upon average temperature during a period of average solar illumination).

5.2.1.7 Assembly Factor

The assembly factor is a measure of the reduction in solar cell output due to design and assembly processes. Based on a manufacturing estimate for the SAS baseline, this factor is assumed to be .965 for power and 1.000 for voltage.

5.2.1.8 Distribution Loss Factors

Distribution losses include voltage drops and power losses due to blocking diodes, various electrical interconnects on the array, the main bus conductor, and the slip ring assembly. These factors are discussed in the following paragraphs.

5.2.1.8.1 Blocking Diodes

This factor is a measure of the voltage drop and power loss due to blocking diodes (3 in parallel for each array panel). For the SAS baseline, this factor is assumed to be .993 for both power and voltage.

5.2.1.8.2 Solar Cell Interconnects

This factor is a measure of the voltage drop and power loss due to solar cell interconnects. For the SAS baseline, this factor is assumed to be .999 for both power and voltage.

5.2.1.8.3 Module-To-Module Interconnects

This factor is a measure of the voltage drop and power loss due to module-to-

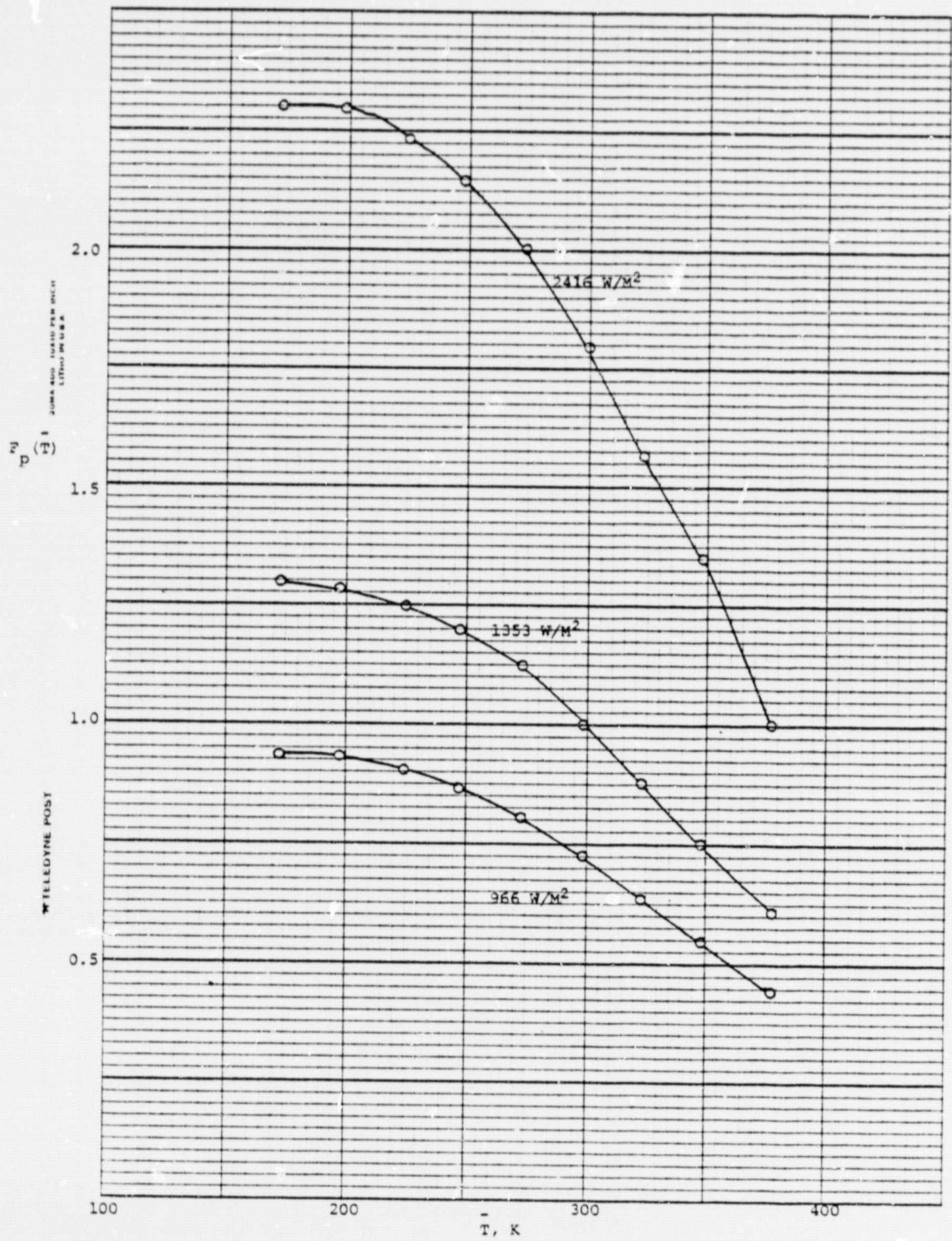


EXHIBIT 5-10. TEMPERATURE DERATING

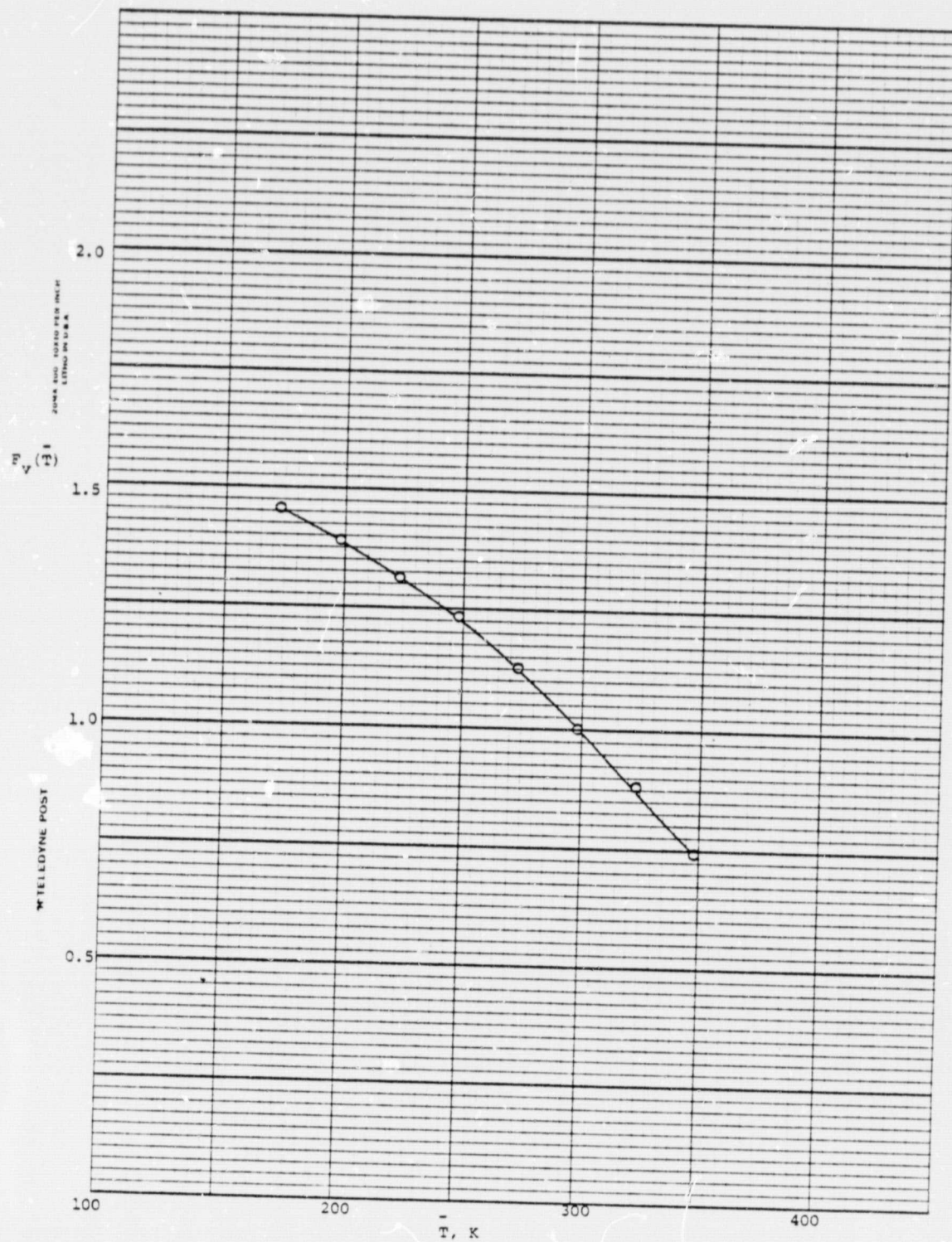


EXHIBIT 5-10. TEMPERATURE DERATING (CONTINUED)

module electrical interconnects. For the SAS baseline, this factor is assumed to be .999 for both power and voltage.

5.2.1.8.4 Panel-To-Panel Interconnects

This factor is a measure of the voltage drop and power loss due to panel-to-panel electrical interconnects. For the SAS baseline, this factor is assumed to be .999 for both power and voltage.

5.2.1.8.5 Main Bus Conductor

This factor is a measure of the voltage drop and power loss due to the main bus conductor. The methodology for determining this factor is as follows:

- Determine sizes of conductors (optimized weight and volume).
- Determine conductor resistance @ 55°C (L/A = constant).
- Determine voltage drop and power loss.
- Determine percentage of total output.

For the SAS baseline, the electrical distribution system for each blanket is as shown in Exhibit 5-11. For an electrical configuration of 12 channels/blanket, there will be a total of 12 pairs of conductors/blanket. The conductor material is 37/36 aluminum/copper alloy.

The Length/Area ratios for the bus conductors are the same throughout the array and have been optimized for each blanket using the following parametric relationship (LSMC-D384250):

$$\frac{L}{A} = \sqrt{\frac{P_D \times C_D \times \Sigma L^2}{N \times I^2 \times \rho}}$$

where P_D = power density of module cross section

C_D = conductor density

ΣL^2 = sum of conductor lengths

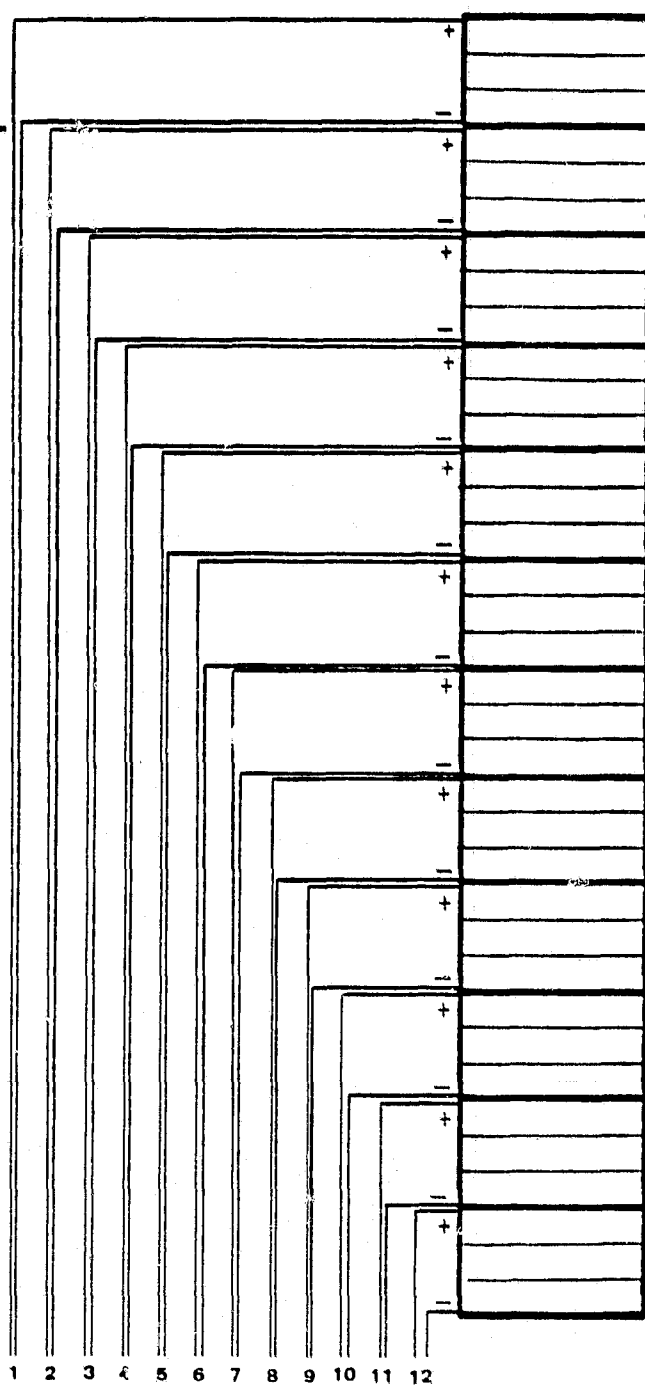
N = number of conductors

I = current

ρ = conductor resistivity

From the resultant L/A ratio, each conductor was sized using a constant cable thickness of .060 in = .15 cm. For insulation, 1 mil kapton + 1 mil high temperature polyester adhesive was used. The total weight of the insulation and adhesive is

EACH CONDUCTOR PAIR -
198V @ 10.0kW



3 PANELS/CHANNEL

MAIN BUS CONDUCTOR

CABLE PAIR	CABLE LENGTH
1	143 131
2	131 119
3	119 108
4	108 97
5	97 85
6	85 74
7	74 63
8	63 51
9	51 40
10	40 27
11	27 17
12	17 6

EXHIBIT 5-11. BLANKET POWER DISTRIBUTION

assumed to be 2.5% of the total conductor weight. For the SAS baseline, the main bus factor is calculated to be .961 for power and .957 for voltage.

5.2.1.8.6 Slip Ring Assembly

This factor is a measure of the voltage drop and power loss due to the slip ring assembly. For the SAS baseline, this factor is assumed to be .988 for both power and voltage.

5.2.1.9 High Voltage Leakage

This factor is a measure of the voltage drop and power loss due to High Voltage leakage currents in a plasma radiation environment. For the SAS baseline, this factor is assumed to be 1.000 for both power and voltage.

5.2.1.10 Temperature Cycling

This factor is a measure of the voltage drop and power loss due to temperature cycling failures. For the SAS baseline, this factor is assumed to be .800 for power and 1.000 for voltage.

5.2.1.11 Equivalent EOL Per-Cell Performance

The equivalent EOL per-cell performance is determined by applying the solar array performance factors to the BOL cell/cover assembly. For the SAS baseline, the cell performance factors are summarized in Exhibit 5-12. This results in an equivalent EOL per-cell performance of .053 watts and .33 volts.

5.2.2 Maintenance Requirements

The maintenance requirements include the array life and also the paralleling of various electrical components to assure design reliability. For the SAS baseline, this results in the following:

- 10-year array life (greater cell and cover degradation factors and temperature cycling losses)
- minimum of 3 cells in parallel
- two sets of interconnects/solar cell
- minimum of 3 blocking diodes in parallel/panel.

CELL PERFORMANCE FACTORS

<u>i</u>	<u>FACTOR</u>	<u>Fv</u>	<u>Fp</u>
1	ASSEMBLY, F_a	1.000	.965
2	RADIATION, F_{rad}	.968	.854
3	TEMPERATURE, F_{top}	.759	.717
4	DIODE, V_d	.993	.993
5	SOLAR CELL IC, V_{sc}	.999	.999
6	MODULE/MODULE IC, V_{mm}	.999	.999
7	PANEL/PANEL IC, V_{pp}	.999	.999
8	MAIN BUS CONDUCTORS, V_{mb}	.957	.961
9	SLIP RING CONDUCTORS, V_{sr}	.988	.988
10	HIGH VOLTAGE LEAKAGE, F_{leak}	1.000	1.000
11	TEMPERATURE CYCLING, F_{tc}	1.000	.800
TOTALS($\prod_{i=1}^{11}$)		.688	.444

EXHIBIT 5-12

5.2.3 Array Performance Requirements

The array performance requirements determine the number of solar cells required, which in turn determine the size and panel/channel configuration of the array. For the SAS baseline, these requirements are:

- 480 kW Total EOL Power
- 10 kW/channel (48 channels)
- 180 V minimum/channel.

5.2.4 Solar Cell Quantity

The quantity of solar cells is determined by the interaction of the solar array performance requirements and the EOL equivalent per-cell performance. For the SAS baseline, 9,072,000 cells are required to meet the 480 kW array total power requirements EOL.

5.2.5 Transportation Requirements

The transportation requirements influence the array design in two ways:

- Fold-Up Array to fit in Shuttle (fold between panels)
- Size of Panel limited by size of shuttle bay.

For the SAS baseline, this resulted in a panel size of 2.81 m x 17.05 m.

5.2.6 Array Design

The basic array design is a fold-up blanket which fits in the shuttle bay. The resultant building block concept is depicted in Exhibit 5-13. The sizes and quantities of modules, panels, and blankets for the SAS baseline are also summarized in Exhibit 5-13.

5.2.7 Array Materials

Variations in the quantities of the various array materials very significantly affect the life cycle cost for a solar array, particularly one as large as 480 kW EOL (953 kW BOL). The array inputs to the life cycle cost model are summarized in Exhibit 5-14. The SAS baseline input values are also summarized in Exhibit 5-14.

5.2.8 Material Costs

Variations in the per unit material costs also significantly effect the array LCC. The costs of materials for the SAS baseline are also summarized in Exhibit 5-14.

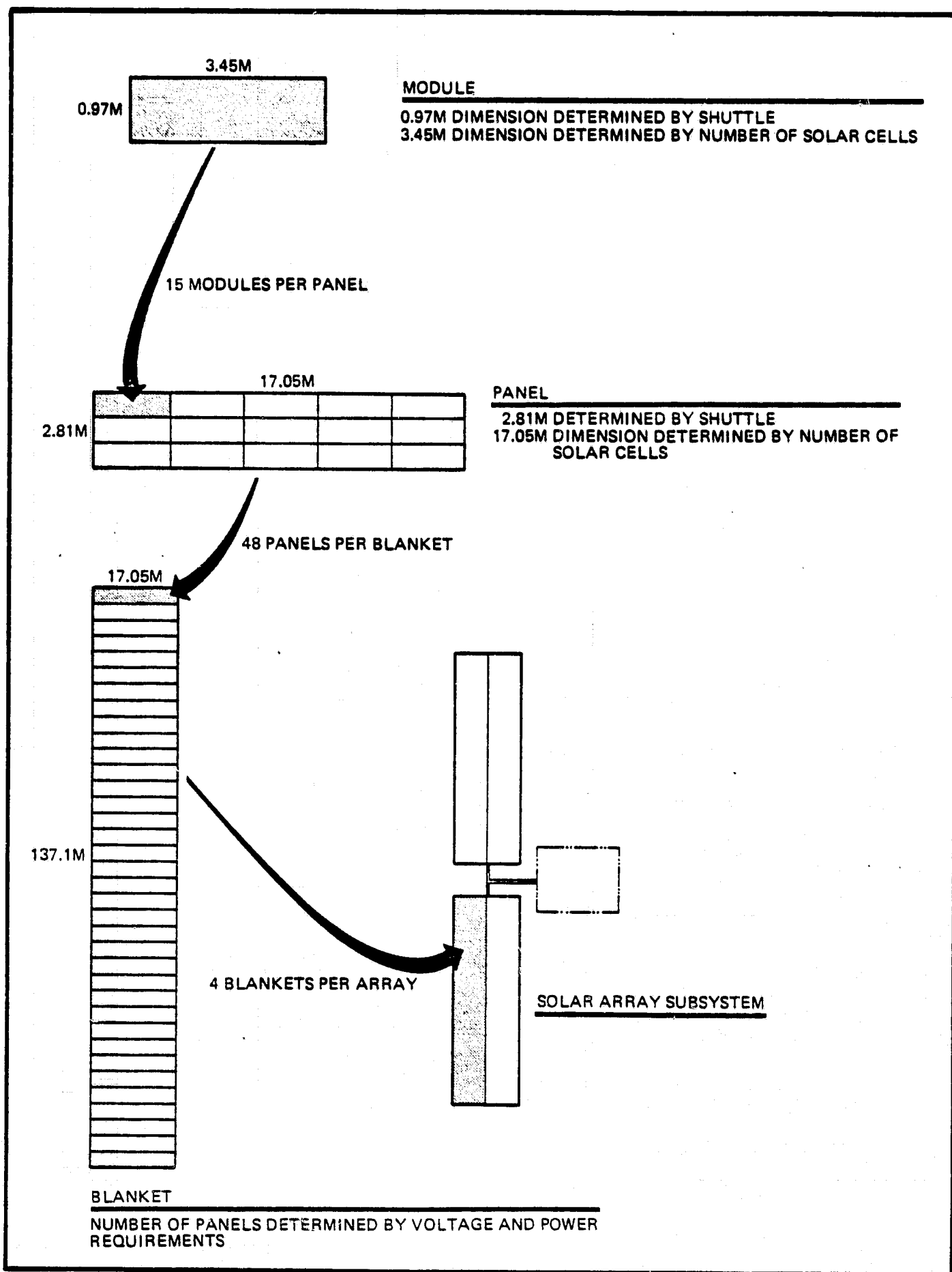


EXHIBIT 5-13. ARRAY DESIGN

BASELINE INPUTS TO LCCM

(1980 \$ In Millions)

● Cost of Labor	
ON EARTH	\$ 20/manhour
IN SPACE	250/manhour
● Cost of Materials	
Cell/Cover Assembly	7.75
Module Substrate	142.29/M ²
Module Assembly (welding materials)	740,000
Mechanical and Electrical Interconnects	10,260/panel
Mechanical and Electrical Interconnects	47,000/blanket
● No. of Cell/Cover Assemblies	9,072,000
● No. of modules	2,880
● No. of panels	192
● No. of blankets	4
● Blanket Weight (4)	11,940 kg.
● Structures Weight	7,778 kg.
● Main Bus Conductors (4)	656 kg.

EXHIBIT 5-14

5.2.9 Array Weight

The array weight determines the space transportation and space assembly/checkout costs. For the SAS baseline, the total blanket weight is 11,940 Kg while the structure's weight is 7,778 Kg, and the weight of the main bus conductors is 656 kg

5.2.10 Array Maintenance

The array maintenance scenario affects the cost of the operations and maintenance phase of LCC, as well as the production phase costs. The primary cost contributions are number of spares required and number of maintenance trips and activities required. For the SAS baseline, 23 sparepanels (12% of total area) is required, and an average of 1.75 maintenance trips/year during the array life of 10 years.

5.2.11 Life Cycle Cost

The life cycle cost consists of three phases:

- DDT&E
- Production
- O&M

The total manufacturing cost during the production phase is basically a quantity related cost, while the NASA cost during the production phase is a weight driven cost. The Life Cycle Costs for the SAS baseline are summarized in Exhibit 5-15.

5.3 Summary

The SAPCM is a very versatile tool which can be used to derive various technology vs LCC relationships. Using assumed relationships, a basic model has been developed. In Section 6.0, the results of varying various parameters are discussed. It should also be noted, that the data bases indicated for radiation flux and radiation degradation, and for temperature derating can be changed, to analyze the effect of newly acquired data in these areas. In addition, the model can be further expanded to address other pertinent factors such as reliability, and other manufacturing and/or maintenance scenarios.

SAS BASELINE LIFE CYCLE COST
(1980 \$ In Millions)

4.0	TOTAL LIFE CYCLE COST	754.5
4.1	DDT&E	153.9
4.2	TOTAL PRODUCTION PHASE COST:	439.9
4.2.1	Total Manufacturing Cost	376.1
4.2.1.1	Manufacturing Labor Cost	34.0
4.2.1.2	Manufacturing Non-Labor Cost	261.7
4.2.2	NASA Cost:	63.9
4.2.2.1	Shuttle Transportation	63.1
4.2.2.2	Space Assembly and Check-Out	.8
4.3	TOTAL O & M COST:	160.7
4.3.1	Total Contractor's Cost	.9
4.3.2	NASA Cost:	159.8
4.3.2.1	Train O & M Crew	2.5
4.3.2.2	Perform Maintenance	11.0
4.3.2.3	Transport Crew to LEO	146.3

EXHIBIT 5-15

6.0 TECHNOLOGY VS. LIFE CYCLE COST

6.1 General

This section summarizes the analysis and results of using the Solar Array Performance and Cost Model (SAPCM) described in Section 5.0 to quantify technology vs. LCC. Conclusions to be drawn from the study results are valid in the vicinity of the baseline under the assumptions, requirements and scenarios of the study and/or as generated previously in this report. Generally, these are:

- Silicon cells, planar array
- Orbit of 444 km, 56° inclination
- Shuttle transportation
- Earth manufacturing scenario
- Manual assembly in space (equipment assisted)
- Space-based maintenance includes personnel for routine maintenance
- DDT&E, program management and SE&I are "wraparound" cost factors
- \$31M/14,000 kg space transportation costs
- Cell/cover assembly costs are historical, but adjusted to 70%, recognizing the large quantity required.

6.2 Methodology

The study results were achieved by addressing each technology area separately and varying key independent parameters in the SACPM to determine resultant variations in life cycle cost. The variations in various intermediate parameters were also observed. The basic methodology consisted of the following:

- Selection and variation of one independent parameter as primary input to the SACPM (e.g., cell thickness, temperature, MTBF, etc.).
- Application of resultant variations in other key parameters as secondary inputs to SACPM (e.g., effects on efficiency, cell degradation, unit material costs, etc.).
- Determination of variations in key intermediate SACPM parameters (e.g., EOL Pmp, quantity of cells, # of panels, etc.)
- Determination of variations in LCC
- Determination of the characteristic equation which quantifies the relationship between the key independent technology parameter and LCC.

It is also important to note that the performance/cost model and/or data base can be easily changed to reflect variations in the array requirements, scenarios and/or assumptions, in effect to perform optimization trade studies.

6.3 Technology Areas

During the course of the study, ten technology areas were addressed using the general methodology discussed above and are discussed in the following paragraphs. These technology areas are listed below.

- Cell Thickness (6.3.1)
- Cover Thickness (6.3.2)
- Average Blanket Temperature (6.3.3)
- Cell Efficiency (6.3.4)
- Cover Degradation (6.3.5)
- Cell Degradation (6.3.6)
- Line Voltage (6.3.7)
- Years Between Overhaul (6.3.8)
- MTBF (6.3.9)
- Cell Cover Assembly Costs (6.3.9)

6.3.1 Cell Thickness vs LCC

The relationships shown in Exhibits 6-1 through 6-3 are for three types of silicon cells: (1) conventional/historical, (2) back surface field and (3) back surface field plus thin diffused top region. The data for all three types of cells were derived from "Semi-Conductors and Semi-Metals" Volume II, Hovel, 1975, Academic Press. The relationships to determine the variations in cell efficiency vs cell thickness and unit cell cost vs. cell thickness and efficiency are indicated for each type of cell. It should be noted that the conventional cells resulted in 5 or more panels/channel, which made a significant contribution to LCC due to the resultant increase in structures weight (e.g., longer booms required). In contrast, the other two categories resulted in only 4 panels/channel except for the 12 mil-12% efficiency cell in category II. One other factor which strongly affects the results is the wide variations in radiation degradation due to variations in cell thickness. Given smaller variations, the effect on life cycle cost would be less pronounced. A composite graph of all three types of cells is shown in Exhibit 6-4.

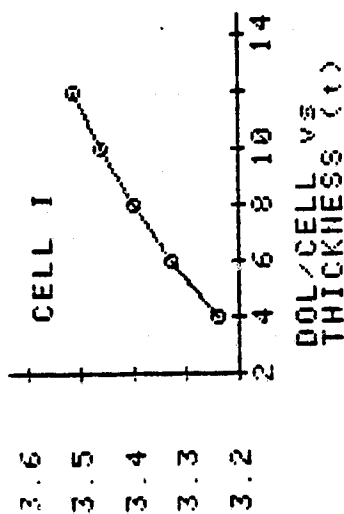
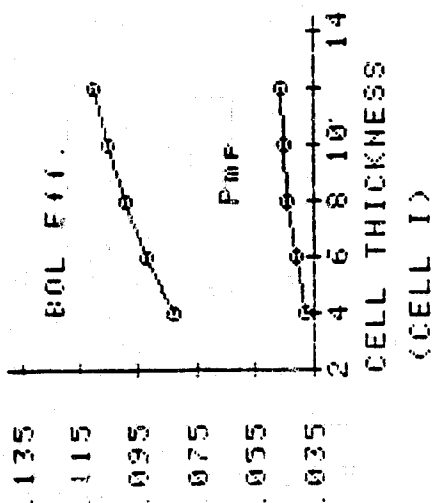
t	n_{BOL}	F_p (Rad)	\bar{T}_{max}	\bar{T}_{min}	$F_p(\bar{T})$	P_{mp}	Q	\$/Cell	Q \$	W	W \$	LCC
12	.110	.800	345.5	340.2	.717	.046	10.4544	3.51	419.728	36.989	110.370	876.282
10	.105	.828	346.0	340.6	.715	.045	10.6848	3.46	426.041	34.924	104.384	876.725
8	.099	.854	346.4	341.1	.713	.044	10.9152	3.40	432.398	33.206	99.369	878.535
6	.092	.878	347.0	341.7	.710	.041	11.7216	3.33	458.576	32.684	97.778	911.728
4	.083	.905	347.7	342.3	.708	.038	12.64896	3.24	502.403	44.380	129.732	1014.032

Cell Thickness = I

$$n_{BOL} = .0582 t^{.256}, \quad 4 < t < 12$$

$$n_{BOL} = 210.0\% \quad n_{BOL} = 1.502 t^{-.313}$$

TABLE 6-1. LCC vs CELL THICKNESS (CONVENTIONAL CELL)



ACTUAL	
EQUATION	CORRELATION
$LCC = 999.305t - 0.056$	0.861
	STANDARD ERROR
	0.009

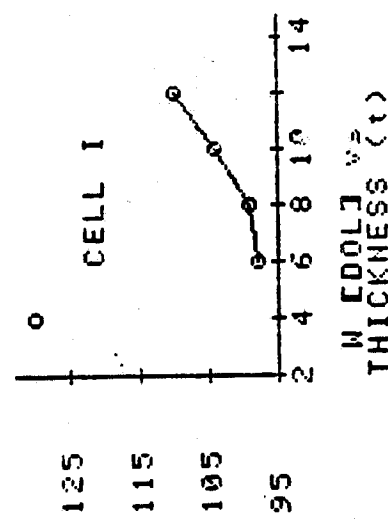
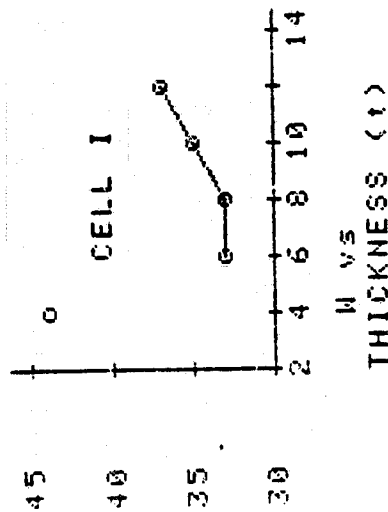
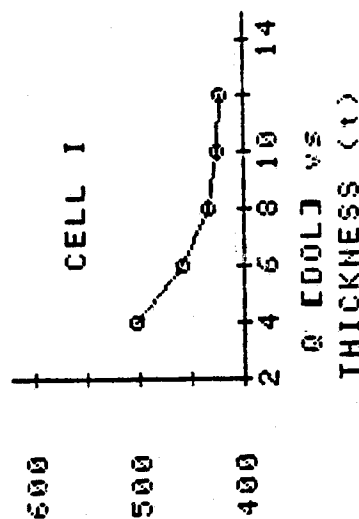
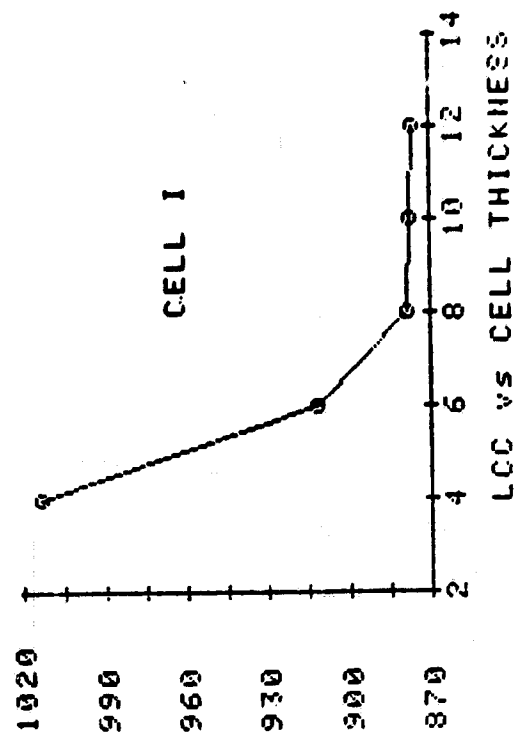
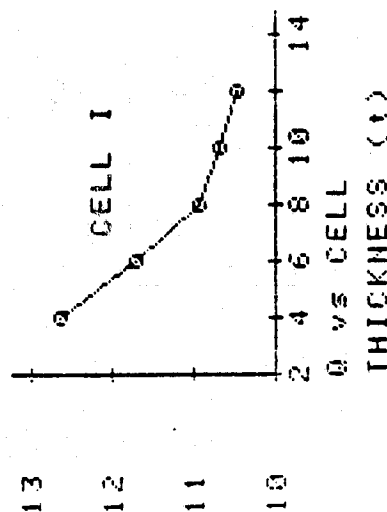


EXHIBIT 6-1. LCC vs CELL THICKNESS

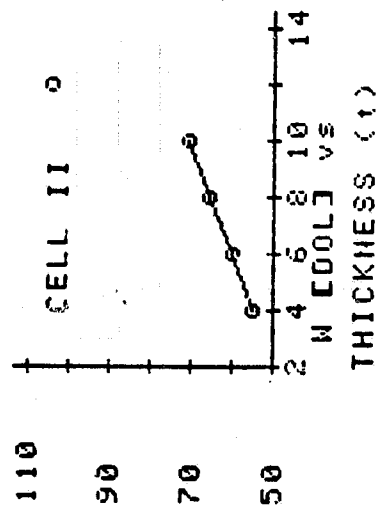
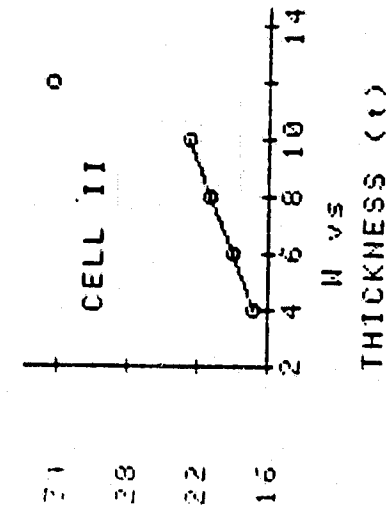
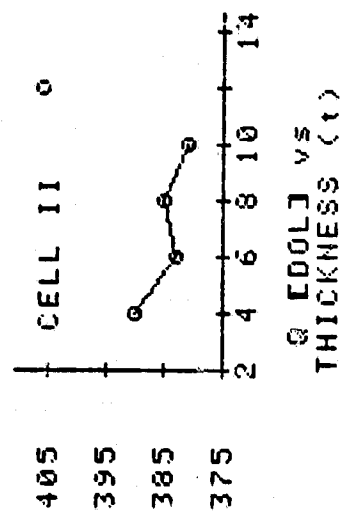
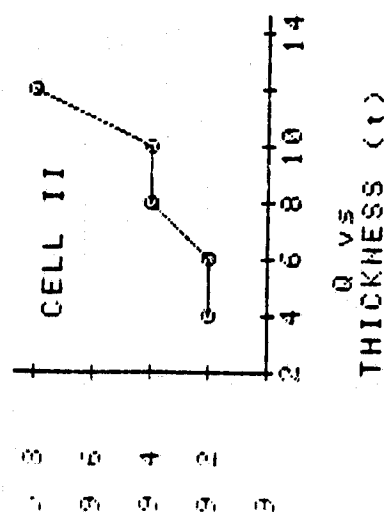
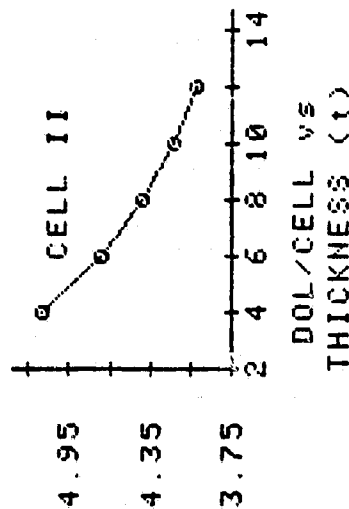
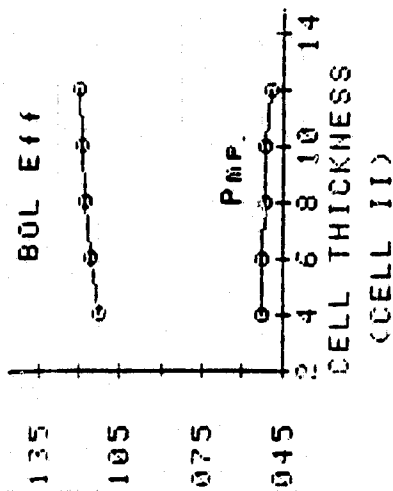
t	n_{BOL}	$F_p \text{ (Rad)}$	\bar{T}_{max}	\bar{T}_{min}	$F_p \text{ (T)}$	P_{mp}	Q	$\$/\text{Cell}$	$Q \text{ \$}$	W	$W \text{ \$}$	LCC
12	.120	.800	345.2	339.8	.719	.049	9.8208	4.00	405.703	34.645	103.660	848.290
10	.119	.828	345.4	340.0	.718	.051	9.4176	4.18	381.272	22.758	70.870	771.042
8	.118	.854	345.6	340.4	.716	.051	9.4176	4.42	385.010	21.080	65.872	769.341
6	.116	.878	346.0	340.7	.715	.052	9.2448	4.72	383.244	18.947	59.556	758.430
4	.113	.905	346.4	341.1	.713	.052	9.2448	5.15	390.108	17.302	54.656	761.081

Cell Thickness - II

$$n_{\text{BOL}} = .105 t^{.0547}, \quad 4 \leq t \leq 12$$

$$\$/\text{Cell} = 210.09 n_{\text{BOL}}^{1.502} t^{-.313}$$

TABLE 6-2. LCC vs CELL THICKNESS (BACK SURFACE FIELD)



ACTUAL	
EQUATION	CORRELATION
LCC=741.451t-0.017	0.811
	STANDARD ERROR
	0.004

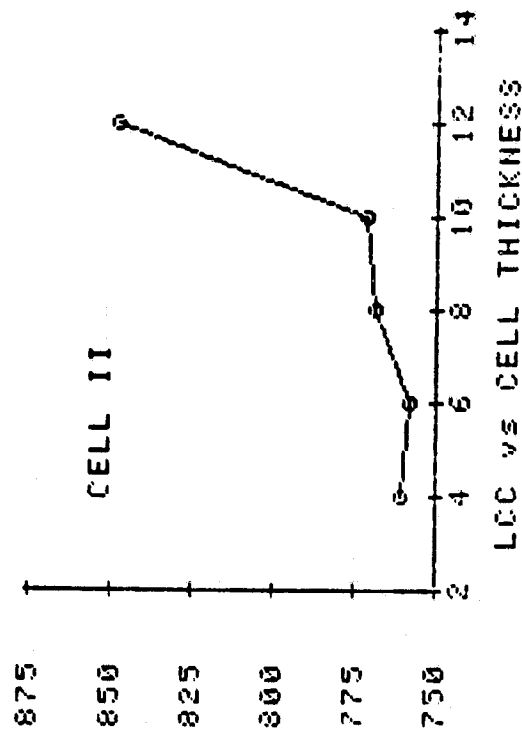


EXHIBIT 6-2 LCC vs CELL THICKNESS

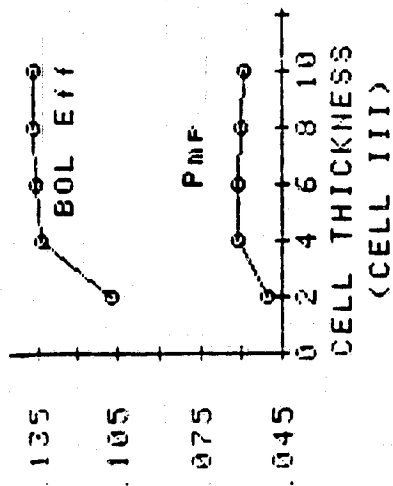
t	n_{BOL}	F_p (Rad)	\bar{T}_{max}	\bar{T}_{min}	F_p (\bar{T})	P_{mp}	Q	\$/Cell	Q \$	W	W \$	LCC
10	.1375	.828	344.7	339.3	.721	.059	8.1504	5.19	350.049	19.822	62.285	717.301
8	.137	.854	344.9	339.6	.720	.060	8.0064	5.53	349.256	18.183	57.404	709.641
6	.136	.878	345.1	339.9	.718	.061	7.8912	5.99	350.927	16.332	51.933	704.511
4	.134	.905	345.5	340.3	.717	.061	7.8912	6.65	360.081	14.911	47.703	711.158
2	.107	.937	347.0	341.6	.711	.050	9.6192	5.89	416.888	16.197	51.324	792.763

Cell Thickness - III

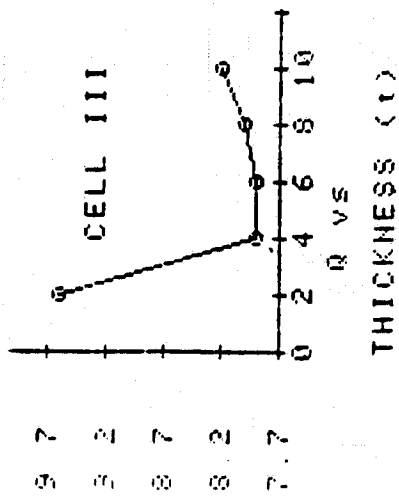
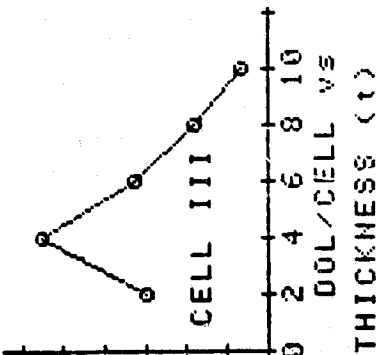
$$n_{BOL} = .1289 \quad t^{.0281}, \quad 4 \leq t \leq 10$$

$$$/Cell = 210.09 \quad n_{BOL}^{1.502} \quad t^{-.313}$$

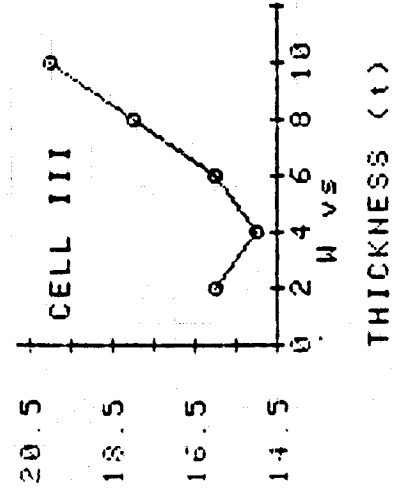
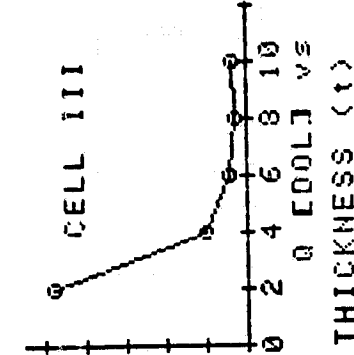
TABLE 6-3. LCC vs CELL THICKNESS (BACK SURFACE FIELD & THIN DIFFUSED TOP REGION)



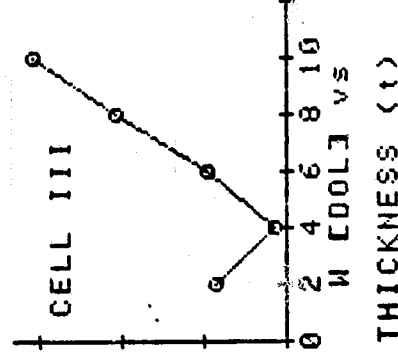
6.8
6.2
5.6
5



405
375
345



62
57
52
47



ACTUAL	
EQUATION	CORRELATION
LCC=699.099(0.009	0.463
	STANDARD ERROR
	0.006

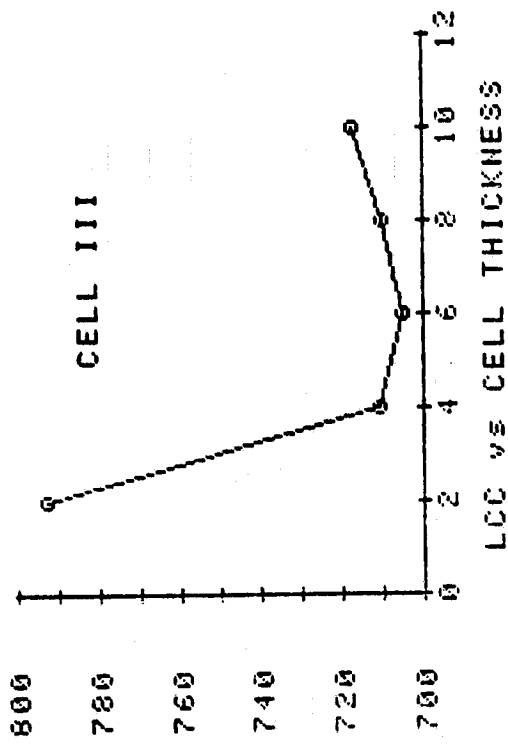


EXHIBIT 6-3. LCC vs CELL THICKNESS

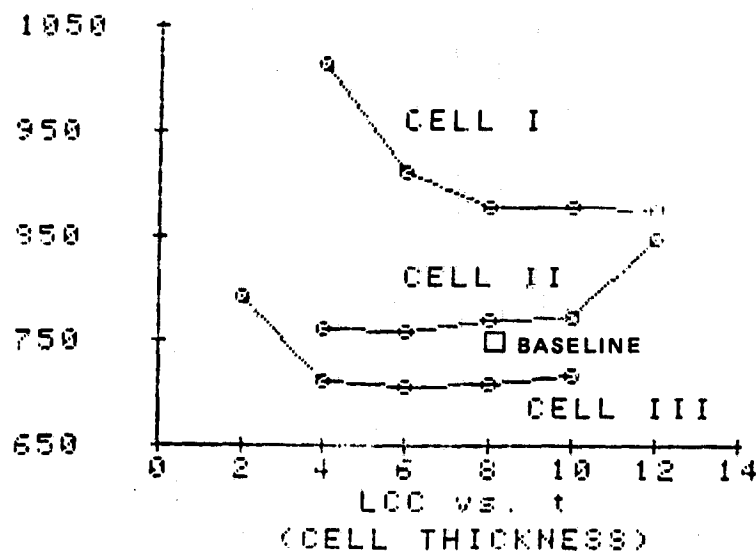


EXHIBIT 6-4. COMPOSITE CELL THICKNESS vs LCC

As seen in the composite, the cell thickness relationships all show a strong influence on LCC, and more importantly the advantages of the back field, thin diffused top region cell. For this type of cell, thickness of 6 mils is optimum.

The deviation of the data points from a smooth curve fit are a result of the number of panels required per power channel which in turn is a result of the Shuttle payload bay dimensional constraints. The SAS baseline is plotted as a reference point ($t=8$ mil, $\eta_{BOL} = .122$).

6.3.2 Cover Thickness vs LCC

The relationship shown in Exhibit 6-5 for cover thickness, displays a strong influence on LCC in the vicinity of four mils, a somewhat reduced influence near the baseline (eight mils), and with little gain above 12 mils. An increase in cover thickness has three effects on LCC: (1) increased weight of array, (2) reduction of degradation rate of cell, and (3) decrease in blanket mean temperature. The variations in radiation degradation are less pronounced due to cover thickness variations than for cell thickness variations. The relationship of unit cover cost versus cover thickness is as indicated. All configurations are based on 4 panels/channel which result in reasonably smooth curves for all parameters indicated.

6.3.3 Blanket Temperature vs LCC

The relationship shown in Exhibit 6-6 shows a strong influence on LCC due to changes in the mean blanket temperature. This derives basically from the change

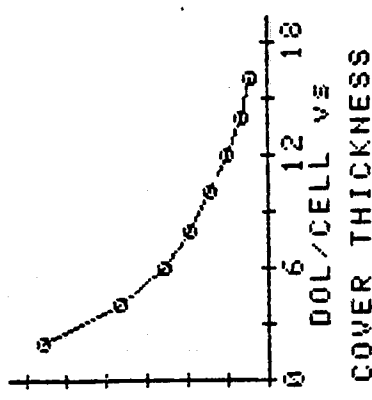
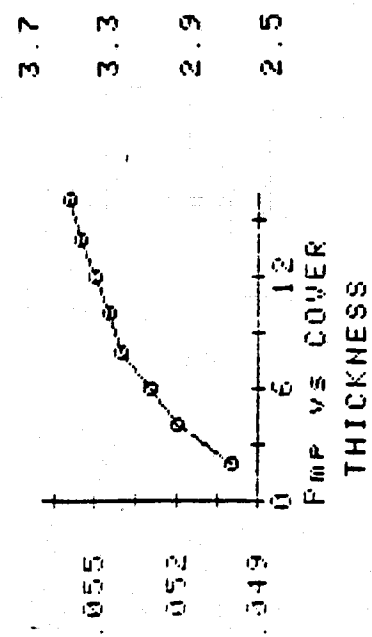
t	F_p (Rad)	\bar{T}_{max}	\bar{T}_{min}	$F_p(\bar{T})$	P_{mp}	Q	\$/Cover	Q \$	W	W \$	LCC
16	.877	343.8	338.3	.726	.056	8.5824	2.58	352.288	25.619	79.520	743.591
14	.875	344.1	338.8	.723	.0555	8.6688	2.63	356.121	24.789	77.005	745.370
12	.872	344.5	339.1	.722	.055	8.7552	2.70	360.060	23.639	73.578	746.061
10	.868	344.7	339.75	.719	.0545	8.8128	2.78	363.139	22.418	69.939	745.305
8	.862	345.1	339.8	.719	.054	8.8992	2.88	367.599	21.223	66.376	746.516
6	.854	345.4	340.2	.717	.053	9.0720	3.02	376.100	20.374	63.808	754.526
4	.839	346.0	340.6	.715	.052	9.2448	3.23	385.657	19.212	60.344	762.751
2	.812	346.5	341.0	.713	.050	9.6192	3.61	406.022	18.446	58.021	787.108

$$$/Cover = 4.04 t^{-.162}$$

$$cc = .945$$

$$se = .036$$

TABLE 6-5. LCC vs COVER THICKNESS



ACTUAL	
EQUATION	CORRELATION
LCC-794.780t-0.026	0.948
	STANDARD ERROR
	0.006

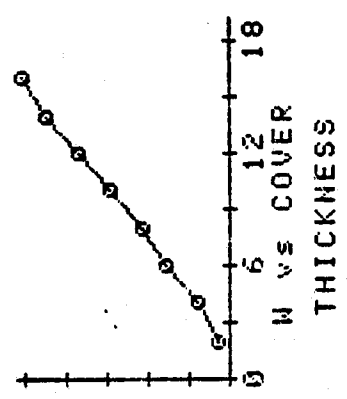
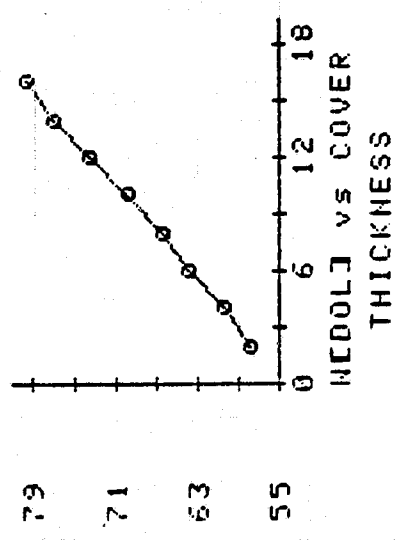
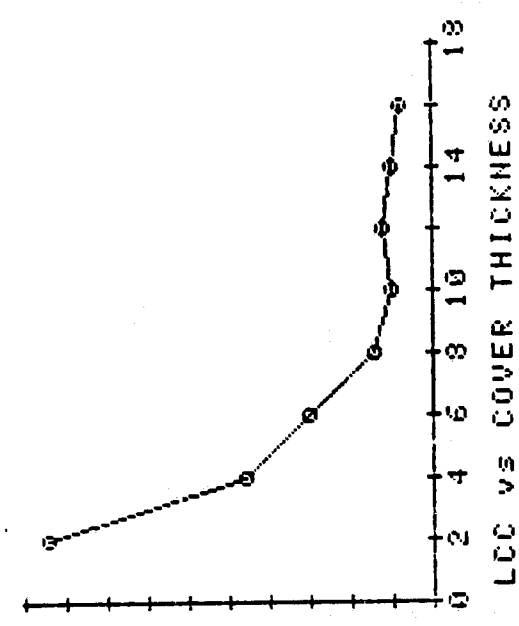
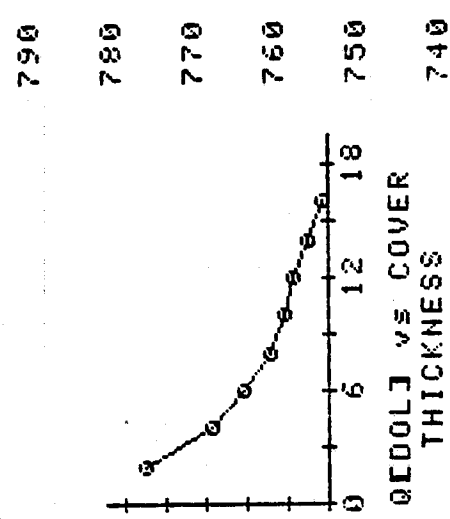
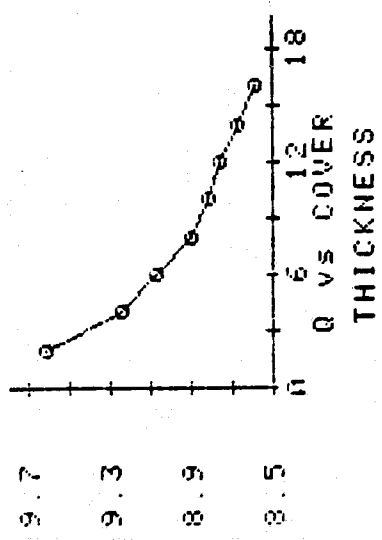
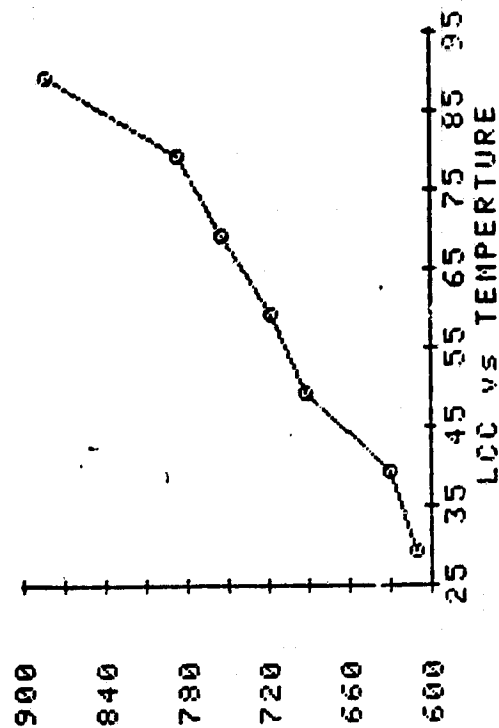
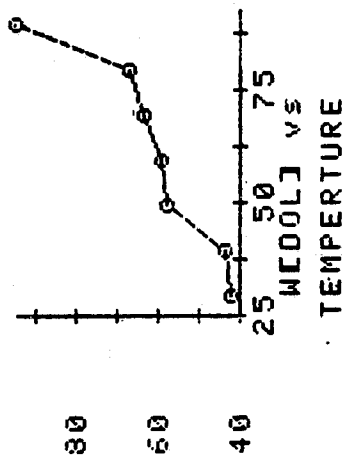
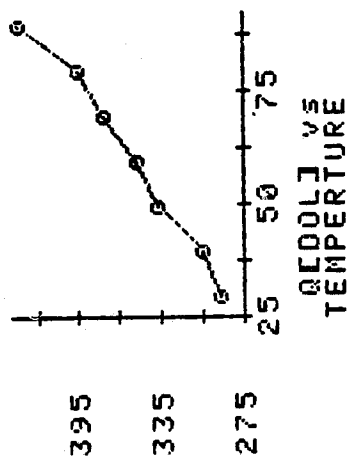
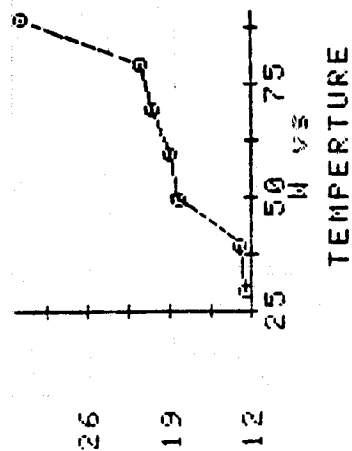
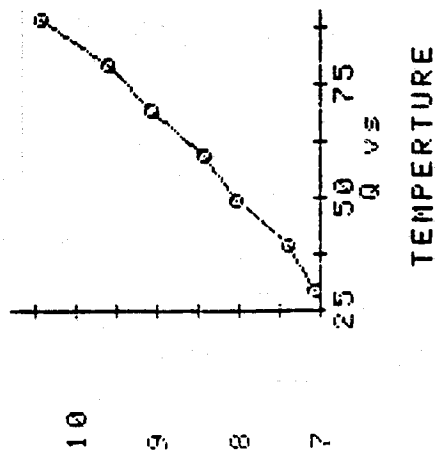
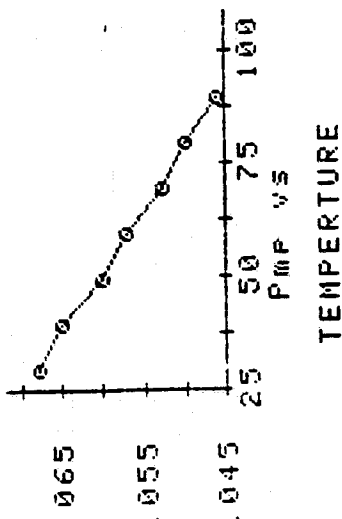


EXHIBIT 6-5. LCC vs COVER THICKNESS

T ^o C	P _{mp}	Q	W	Q \$	W \$	LCC
89.2	.046	10.4400	31.766	439.275	95.256	882.267
79.2	.050	9.6192	21.411	396.393	66.841	785.994
69.2	.053	9.0720	20.374	376.100	63.808	754.526
59.2	.057	8.4384	18.933	352.427	59.612	716.903
49.2	.060	8.01792	18.287	336.911	57.697	693.371
39.2	.065	7.3872	13.074	303.583	43.746	629.544
29.2	.068	7.0632	12.518	291.593	42.076	611.103

TABLE 6-6. LCC vs TEMPERATURE



EQUATION		ACTUAL	
C ₁	LCC=243.007T-0.258	CORRELATION	
		0.992	
		STANDARD ERROR	
		0.006	

EXHIBIT 6-6. LCC vs TEMPERATURE

in cell efficiency with temperature (\$3.2M per 1°C). Of the technology areas addressed, temperature proved to have one of the greatest effects on LCC. As can be seen in the exhibit, the C₁ curve is for arrays with 4 panels/channel. The C₂ curve is for 3 panels/channel. The 89.2° point results in 5 panels/channel. It should be noted that the cost to achieve any reduction in temperature is not included in the LCC. Only the resultant effect of the reduction is included.

6.3.4 Cell Efficiency vs LCC

The relationship shown in Exhibit 6-7, as expected, shows a strong influence on LCC. In the vicinity of the baseline, the slope is \$46M per 1% change in cell efficiency (measured at BOL). The basic effect is on baseline quantities, weights, and cell unit costs. The relationship of unit cell cost vs. cell efficiency is as indicated. The study results also indicated the following relationship between EOL Pmp and the number of panels/channel.

<u>EOL Pmp (w)</u>	<u>#Panels/Channel</u>
.064 - .093	3
.050 - .063	4
.040 - .049	5
.034 - .039	6

6.3.5 Cover Degradation vs LCC

The relationship shown in Exhibit 6-8 displays a medium/strong influence on LCC. The slope in the vicinity of the baseline optical factor (.885) is about \$10M per 1% change of the factor. The cover unit cost variation as indicated is more than offset by the substantial reductions in weight, dimensions and number of cells in the baseline. The effect of cover degradation is two-fold: (1) the illumination reaching the solar cell is effected; (2) the illumination effect in turn effects the temperature derating. Hence, the effect of cover degradation on LCC is greater than the effect of cell degradation, which is discussed in paragraph 6.3.6. All array configurations have 4 panels/channel except the two extremes (.974 & .840), which have 4 and 5 respectively.

6.3.6 Cell Degradation vs LCC

The relationship shown in Exhibit 6-9 displays a medium influence on LCC. The slope is nearly constant at \$5.4M per one percent change for all values of the

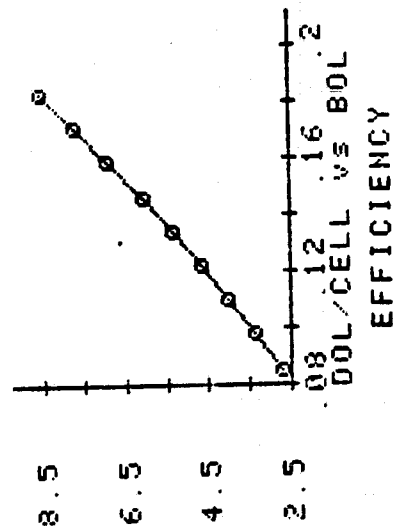
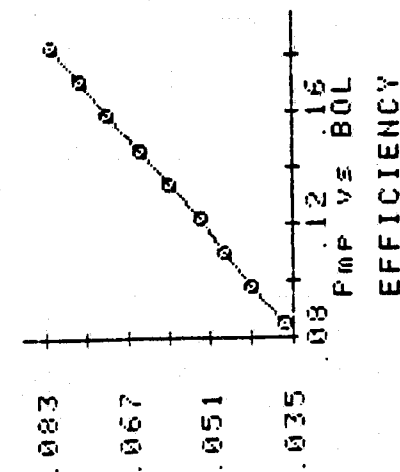
η_{BOL}	P_{mp}	# Panels/ Channel	Q	W	\$/Cell	Q \$	W \$	LCC
.183	.082	3	5.85792	10.687	8.55	288.665	36.506	599.631
.171	.076	3	6.32448	11.520	7.72	299.741	39.010	617.964
.159	.071	3	6.76512	12.139	6.92	308.573	40.892	682.428
.146	.065	3	7.3872	13.308	6.09	323.117	44.400	656.798
.134	.059	4	8.1504	18.369	5.35	352.100	57.958	714.228
.122	.053	4	9.0720	20.374	4.65	376.100	63.808	754.526
.110	.048	5	10.0224	30.740	3.98	411.437	92.307	840.704
.098	.043	5	11.1744	33.668	3.35	440.365	100.706	891.096
.085	.037	6	12.99456	54.558	2.70	505.251	158.695	1056.977

$$$/Cell = 109.6 \eta_{BOL} \quad 1.502$$

$$CC = .9998$$

$$SE = .004$$

TABLE 6-7. LCC vs CELL EFFICIENCY



ACTUAL	
EQUATION	CORRELATION
LCC-166.5417 BOL	0.989
	STANDARD ERROR
	0.027

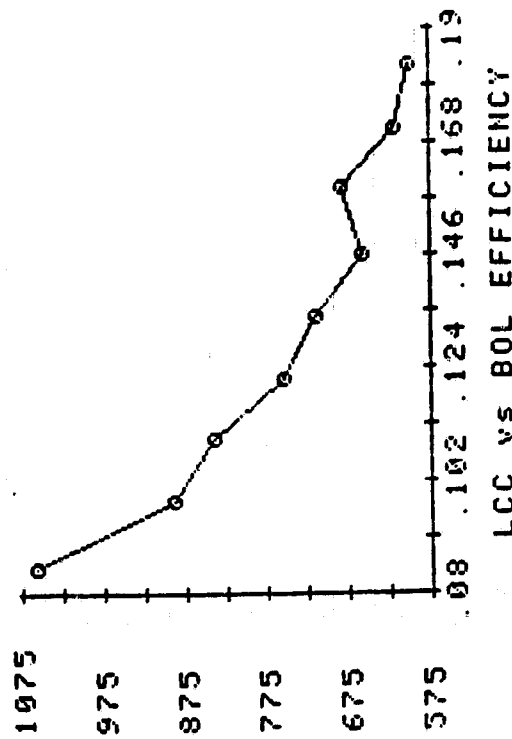
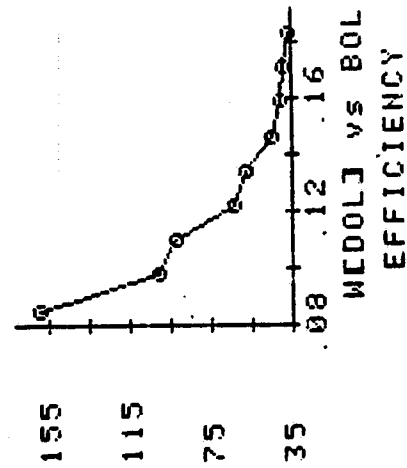
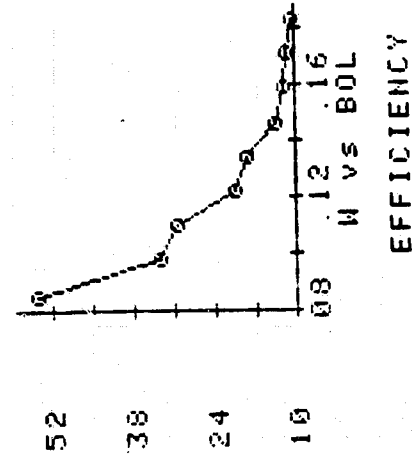
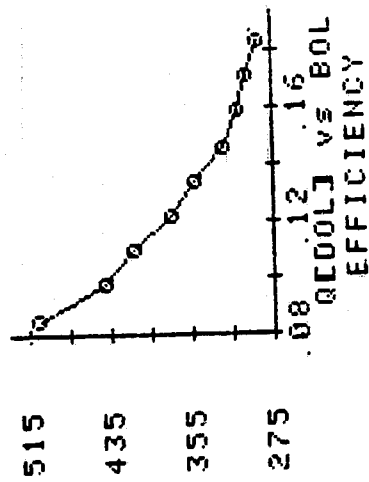
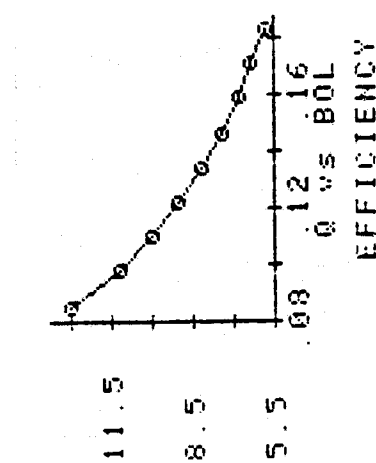
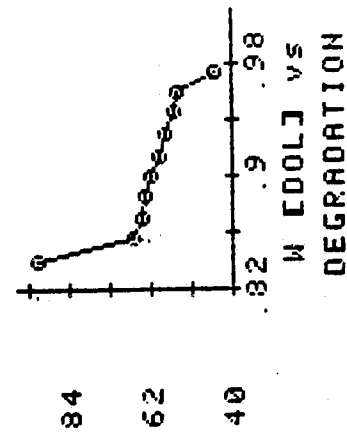
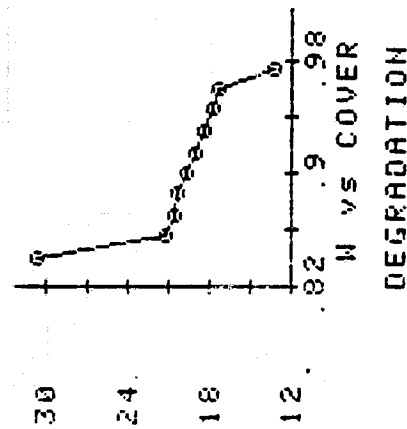
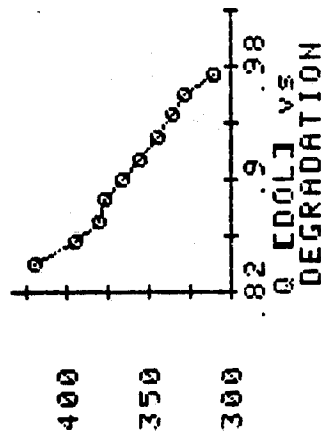
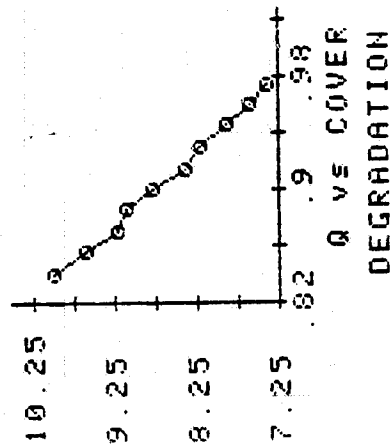
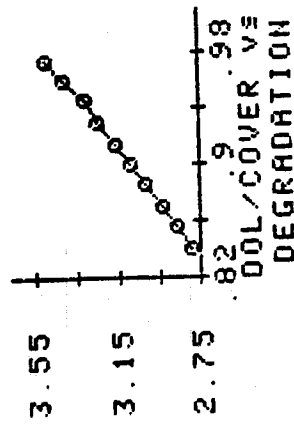
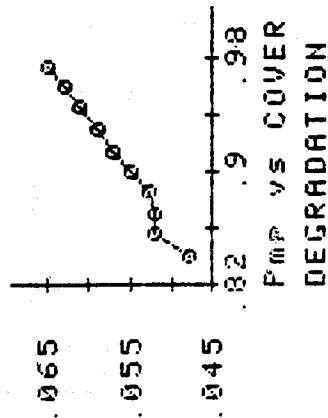


EXHIBIT 6-7. LCC vs BOL EFFICIENCY

F_c	P_{mp}	Q	W	$\$/Cover$	$Q \$$	$W \$$	LCC
.974	.065	7.3872	13.308	3.49	310.085	44.400	639.205
.960	.063	7.6320	17.412	3.41	327.925	55.152	677.804
.945	.061	7.8912	17.733	3.33	336.457	56.107	690.611
.930	.059	8.1504	18.369	3.25	345.133	57.958	704.823
.914	.057	8.4384	18.998	3.17	354.763	59.793	720.301
.900	.055	8.7552	19.693	3.10	365.561	61.820	737.614
.885	.053	9.0720	20.374	3.02	376.100	63.808	754.526
.870	.052	9.2448	20.599	2.94	381.088	64.477	762.163
.855	.052	9.6192	21.332	2.87	393.712	66.621	782.100
.840	.048	10.0224	30.740	2.79	419.456	92.307	851.530

$$\$/Cover = 3.628 F_c^{1.502}$$

TABLE 6-8. LCC vs COVER DEGRADATION



ACTUAL	
EQUATION	LCC=644.964F _c -1.240
CORRELATION	0.998
STANDARD ERROR	0.003

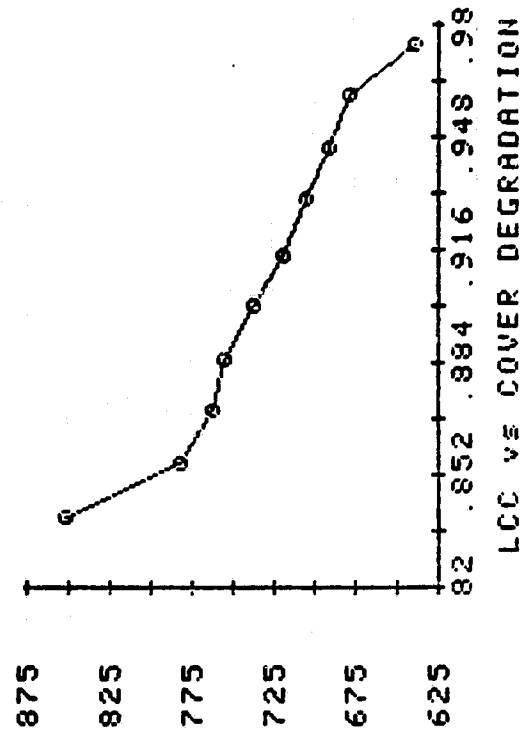
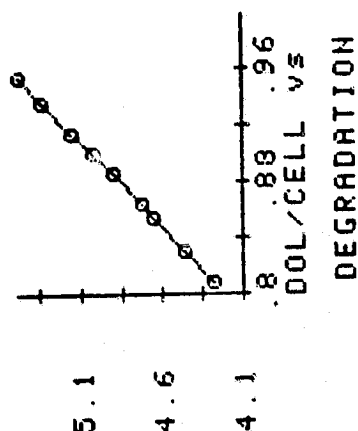


EXHIBIT 6-8. LCC vs COVER DEGRADATION

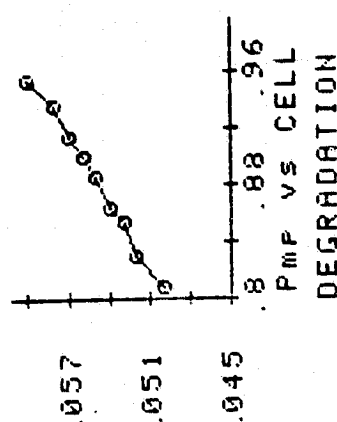
F_p (Rad)	P_{mp}	Q	W	\$/Cell	Q \$	W \$	LCC
.953	.060	8.0064	18.157	5.48	348.516	57.332	708.545
.935	.058	8.2944	18.806	5.33	357.437	59.223	723.141
.914	.057	8.4384	18.986	5.15	360.128	59.758	727.496
.899	.056	8.5824	19.165	5.02	363.505	60.293	732.777
.885	.055	8.7552	19.687	4.91	368.424	61.803	741.456
.864	.054	8.8992	19.873	4.73	370.857	62.356	745.488
.854	.053	9.0720	20.374	4.65	376.100	63.808	754.526
.829	.052	9.2448	20.605	4.45	379.073	64.494	759.465
.808	.050	9.6192	21.352	4.28	389.872	66.677	776.991

$$F_p \text{ (Rad)} = 5.894 \text{ } F_p \text{ (Rad)}^{1.502}$$

TABLE 6-9. LCC vs CELL DEGRADATION



5.1
4.6
4.1



ACTUAL

EQUATION	CORRELATION
$LCC = 694.923F_p(\text{Rad}) - 0.506$	0.989
	STANDARD ERROR 0.004

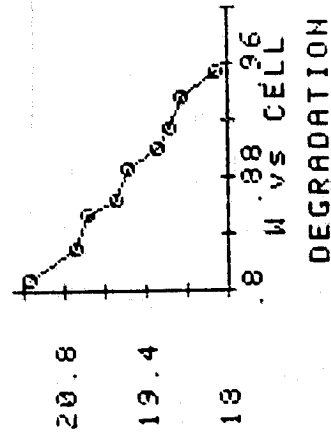
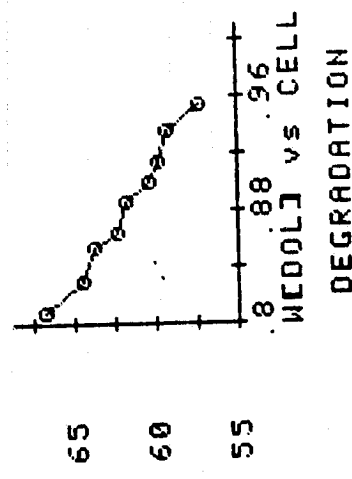
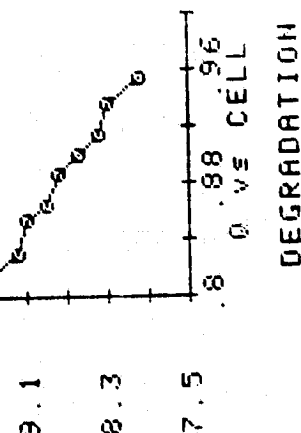
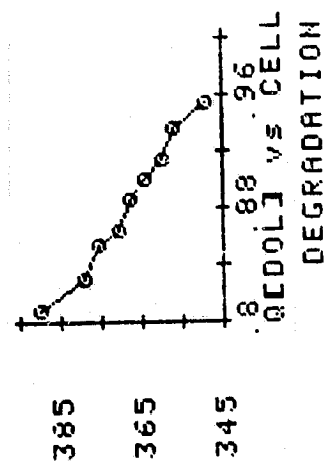
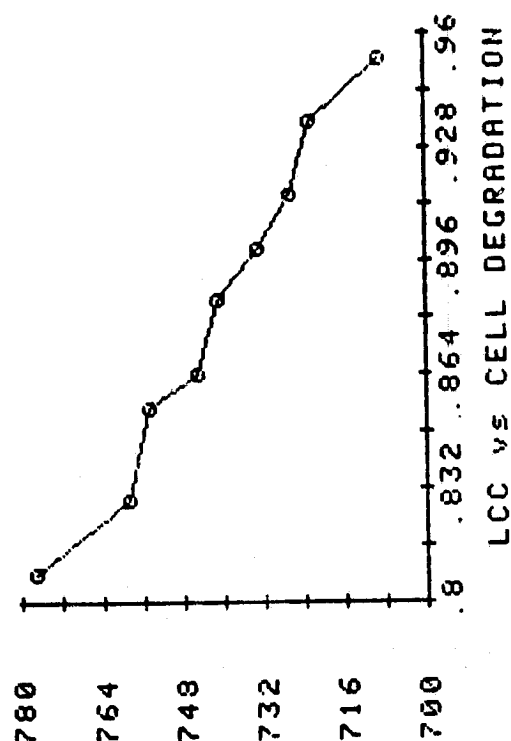


EXHIBIT 6-9. LCC vs CELL DEGRADATION

degradation factor. The basic effects, as the factor increases, are due to quantity, weight and dimensional reductions. The unit cell cost increases with degradation resistance but does not substantially offset the other basic effects. All array configurations have 4 panels/channel.

It should be noted that the basic methodology used to achieve the results indicated could be applied to any solar cell performance parameter with similar results. In addition, the results obtained here can be used in conjunction with the cell thickness results to determine the effect of a smaller variation cell degradation vs cell thickness over the array lifetime.

6.3.7 Line Voltage vs LCC

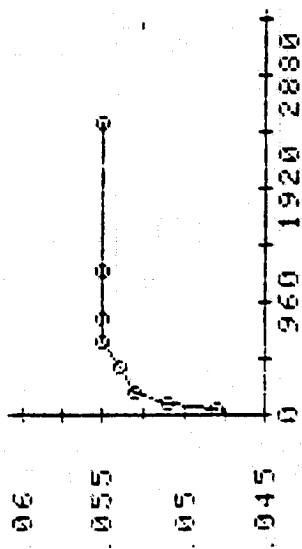
The relationship shown in Exhibit 6-10 displays a moderate influence on LCC in the low (40 to 100 volts) range, and very weak influence above 400 volts. For each data point, an array weight and size was calculated for an optimum selection of I^2R losses versus blanket area. The variations in line voltage were achieved by simply increasing the number of panels/channel (e.g., connected in series) while decreasing the total number of channels. This means that the total array size and the total current through the main bus conductors does not significantly change. It should be noted that these curves do not include the effect of high voltage leakage which could prove to have a quite drastic effect on the results.

6.3.8 Years Between Overhaul vs LCC

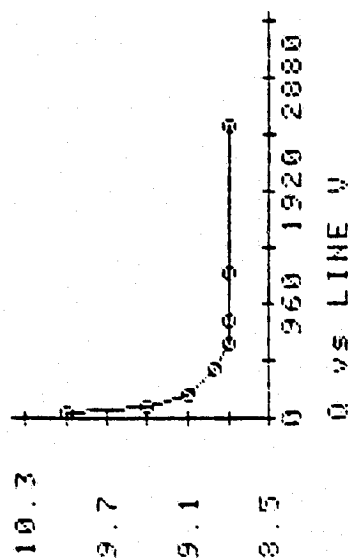
The relationship shown in Exhibit 6-11 displays an optimum life (or time between blanket changeout) near the baseline 10 years. The transportation costs of earlier overhauls dominate the reduced blanket area required for the baseline design. The cost of achieving the longer life design was not quantified (effect on DDT&E and material costs, for example). It should be noted that although the array quantities and weights would be smaller for a shorter array lifetime, the totals required to be manufactured and sent into space would increase drastically as the lifetime decreases. (e.g., four times as much is required for 2.5 years between overhaul.) This leads to the conclusion that the array should be designed for a minimum of overhaul during its projected period of operation.

Line V	P _{mp}	Q	W	Q \$	W \$	LCC
51.8	.048	10.0224	26.742	413.884	81.778	829.794
93.9	.051	9.4176	22.386	389.654	69.501	780.509
198.0	.053	9.0720	20.374	376.100	63.808	754.526
404.4	.054	8.8992	19.329	369.267	60.844	741.300
612.0	.055	8.7552	18.971	363.892	59.813	732.652
818.4	.055	8.7552	18.880	363.842	59.560	732.243
1231.2	.055	8.7552	18.794	363.798	59.321	731.861
2469.6	.055	8.7552	18.703	363.752	59.069	731.458

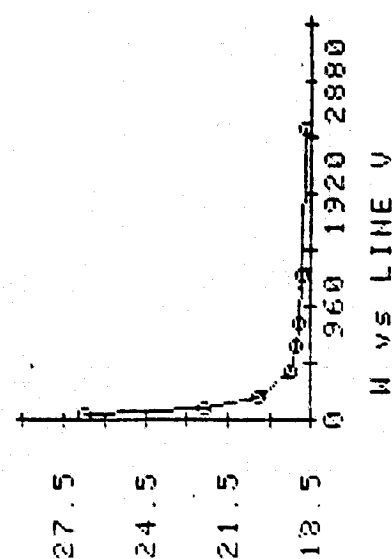
TABLE 6-10. LCC vs LINE VOLTAGE



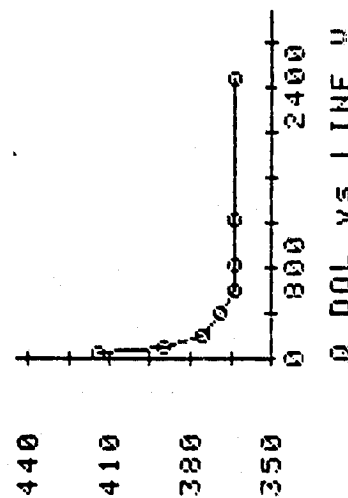
Pmf vs LINE V



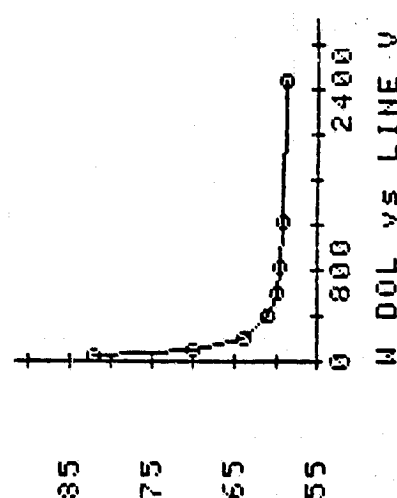
W vs LINE V



W DOL vs LINE V

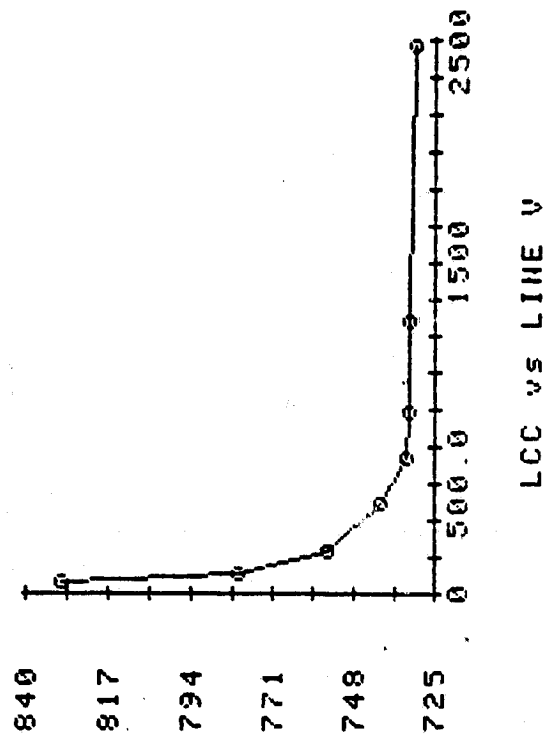


W DOL vs LINE V



W DOL vs LINE V

ACTUAL	
EQUATION	CORRELATION
LCC-904.918-0.031	0.893
	STANDARD ERROR
	0.022

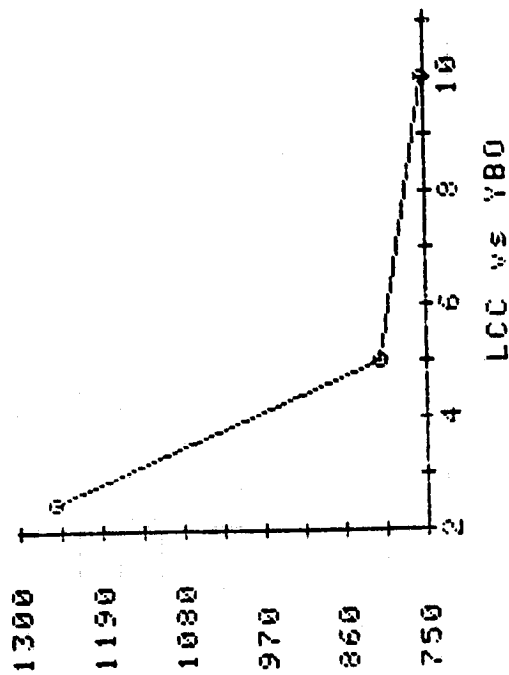
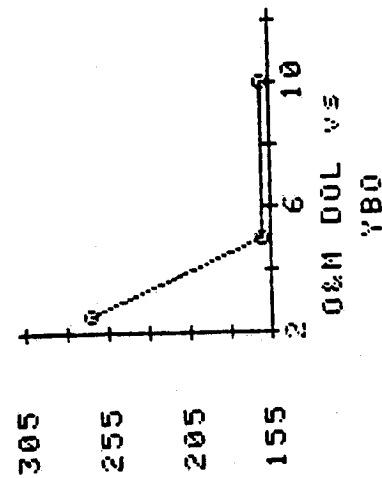
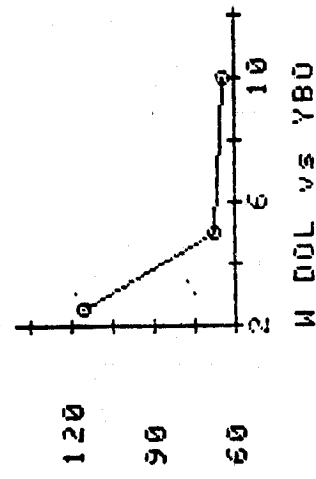
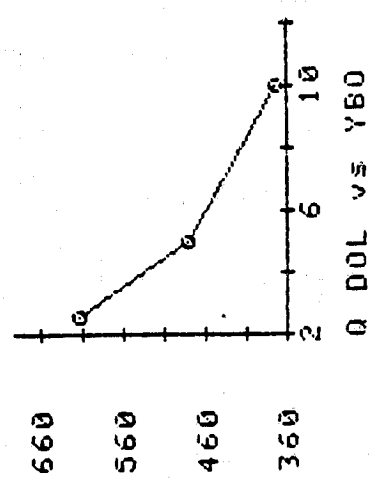
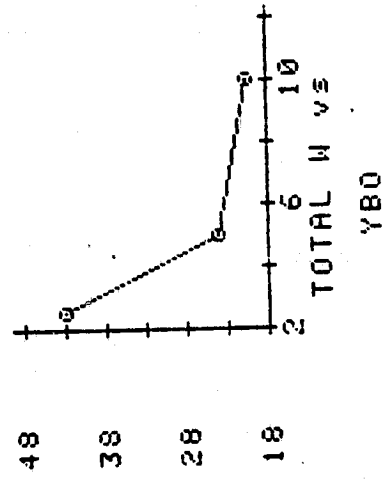
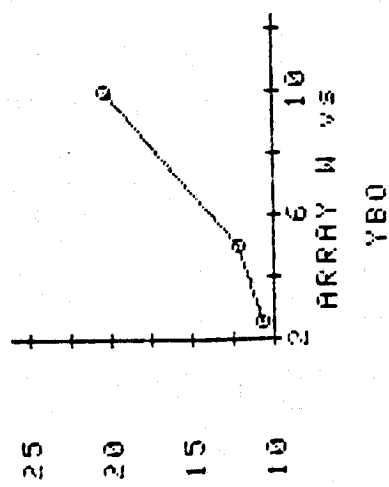
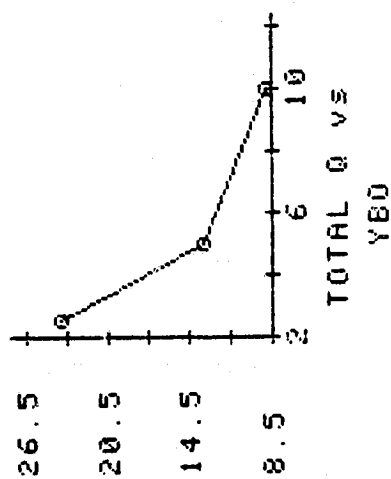
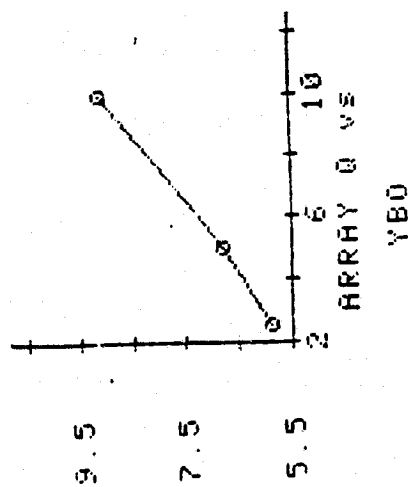


LCC vs LINE V

EXHIBIT 6-10. LCC vs LINE V

Yrs	Array Q	Array W	Total Q	Total W	Q \$	W \$	O&M \$	LCC
2.5	5.93568	10.774	23.74272	43.096	614.838	115.764	265.483	1251.796
5	6.76512	12.150	13.53024	24.300	483.334	67.716	160.650	813.151
10	9.0720	20.374	9.0720	20.374	376.100	63.808	160.650	754.526

TABLE 6-II. LCC vs YEARS BETWEEN OVERHAUL



ACTUAL	
EQUATION	CORRELATION
LCC=1648.321-0.365	0.926
	STANDARD ERROR
	0.146

EXHIBIT 6-11. LCC vs YBO

6.3.9 Mean Time Between Failures vs LCC

The relationship shown in Exhibit 6-12 displays a moderate influence on LCC near the baseline. For the baseline design, 23 panel failures over the 10 year life (MTBF = 5,000 Hrs.) were assumed for the purpose of determining spare panel quantities. A higher failure rate means more spares and increased space transportation costs. The primary result indicates a need to look at this area further by including a more rigorous study of the relationship between the MTBF and number of spares, and particularly the effect on DDT&E phase costs.

6.3.10 Cell and Cover Assembly Unit Costs vs LCC

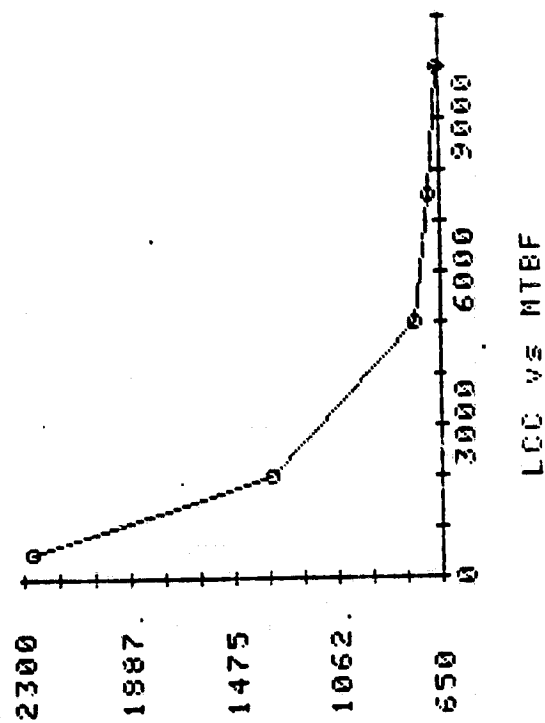
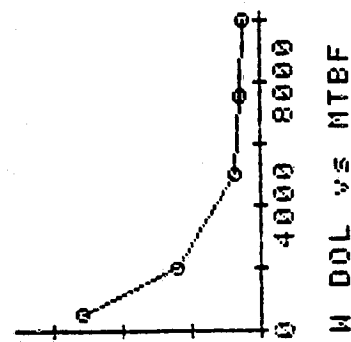
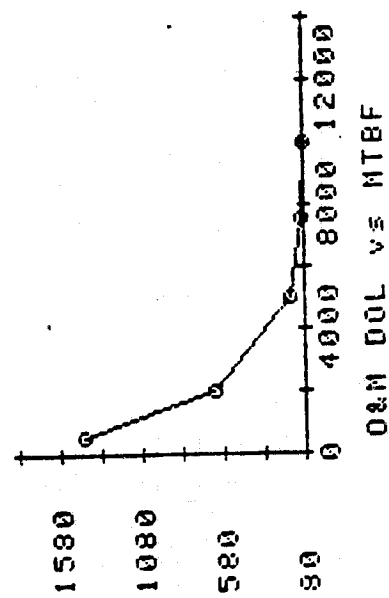
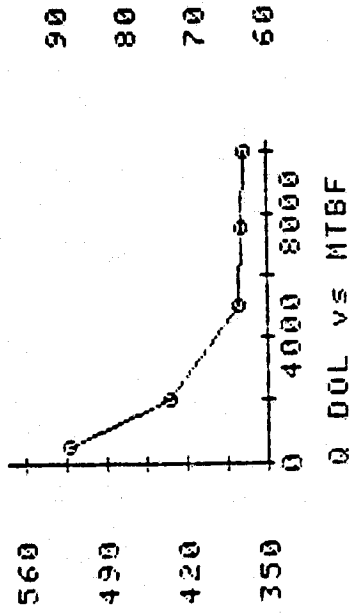
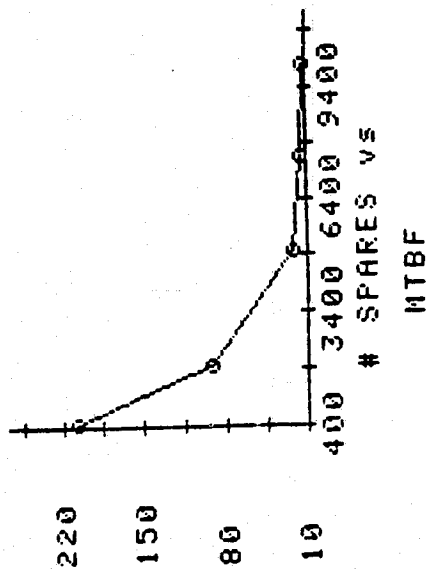
The relationship shown in Exhibit 6-13 gives a slope of \$22M savings in LCC for each dollar reduction in cell and cover assembly unit costs. The results in this technology area indicate what benefits could be realized in LCC reduction, simply by reducing the unit cost of the cell and/or cover. In addition, the relationship between unit cost and LCC indicated here can be used to adjust the results of exercising the corresponding LCC relationship in any or all of the other technology areas.

6.4 Summary

The results of the various technology areas vs LCC are summarized in Exhibit 6-14. It should be emphasized that the slopes (e.g., \$/% change) apply only within the immediate region of the baseline SAS. It should also be noted that while the individual results were obtained by varying only one independent parameter at a time, it is possible to use the various relationships in various combinations. For example, given a solar cell which does not exactly fit one of the cell thickness vs LCC curves, it is possible to adjust the effect of a different efficiency, cell degradation, and/or unit cell cost on the LCC by applying the appropriate relationships in conjunction with one another. However, it should also be emphasized that this method will give only approximate results, and should be used in only relatively simple combinations. To obtain a better composite result, the Solar Array Performance

Hrs	# Spares	Q \$	W \$	O&M	LCC
10,000	12	369.213	62.486	84.247	667.041
7,500	15	371.952	62.847	105.084	692.063
5,000	23	376.100	63.808	160.650	754.526
2,000	92	434.660	72.098	639.900	1324.023
500	207	522.630	85.915	1438.650	2260.186

TABLE 6-12. LCC vs MEAN TIME BETWEEN FAILURES



ACTUAL	
EQUATION	CORRELATION
LCC=33442.048 ^{-0.433}	0.991
	STANDARD ERROR
	0.082

EXHIBIT 6-12. LCC vs MTBF

<u>\$/CCA</u>	<u>Q \$</u>	<u>LCC</u>
10.00	413.225	804.645
7.75	376.100	754.526
5.00	330.725	693.270
3.50	305.975	659.857
2.00	281.226	626.446
1.00	264.726	604.171
.50	256.476	593.033

TABLE 6-13. LCC vs \$/CELL & COVER ASSEMBLY

ACTUAL	
EQUATION	CORRELATION
LCC-607.593\$/CCA 0.099	0.942
	STANDARD ERROR
	0.036

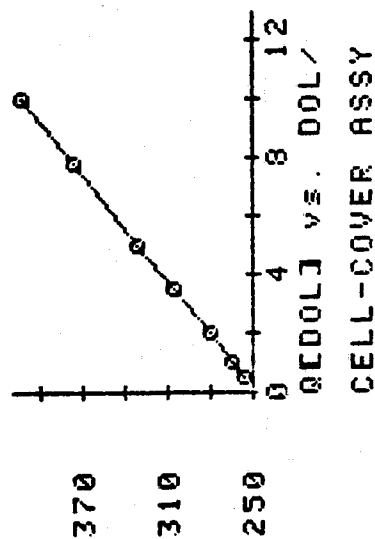
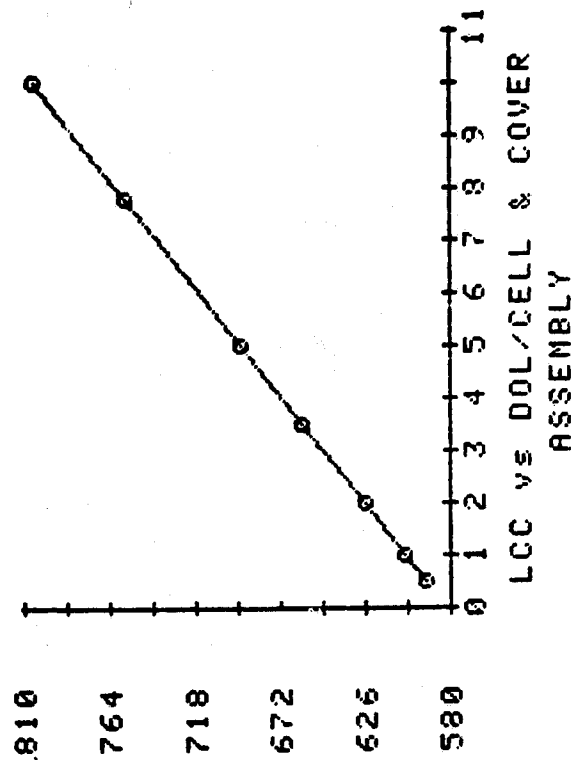


EXHIBIT 6-13. LCC vs DOL/CELL & COVER ASSEMBLY

TECHNOLOGY AREAINFLUENCE ON LCC

CELL THICKNESS	MEDIUM/STRONG - 6 MILS OPTIMUM*
COVER THICKNESS	MEDIUM - LITTLE GAIN ABOVE 12 MILS
BLANKET TEMPERATURE	STRONG - \$3.2M/°C
CELL EFFICIENCY	STRONG - \$46M/1% CHANGE
COVER DEGRADATION	MEDIUM/STRONG - \$10M/1% CHANGE
CELL DEGRADATION	MEDIUM - \$5.4M/1% CHANGE
LINE VOLTAGE	WEAK - LITTLE GAIN ABOVE 400 VOLTS
YEARS BETWEEN OVERHAUL	WEAK - LONGER LIFE BETTER
MTBF	MEDIUM - KEEP MTBF UP, SPARES LOW
CELL COVER ASSEMBLY COSTS	STRONG - \$22M/\$ CELL COVER ASSEMBLY UNIT COST

*RESULTS ARE GIVEN FOR THREE CLASSES OF CELLS (THIS APPLIES TO BSF + THIN
DIFFUSED TOP REGION CELL ONLY).

and Cost Model should be adjusted and/or exercised accordingly.

6.5 Recommendations

The recommendations to be made are in two categories: (1) those based on each technology area/LCC quantified (Section 6.5.1) and (2) general recommendations for further applications of the model and techniques developed for the study (Section 6.5.2).

6.5.1 Specific Technology Recommendations

Cell Thickness - Determine an optimum cell thickness and type of cell (back field, thin diffused top region, etc.) for various array designs, missions and manufacturing and maintenance scenarios.

Cover Thickness - Same as for cell thickness.

Blanket Temperature - Explore the feasibility of various thermal control methods/materials to optimize LCC ($\$3.2\text{M}/^{\circ}\text{C}$).

Cell Efficiency - Perform an in-depth study to model the optimum relationship of cell cost vs. cell efficiency involving various manufacturing scenarios ($\$46\text{M}/1\%$ change in Efficiency).

Cover Degradation - Explore methods to increase cell degradation resistance ($\$10\text{M}/1\%$ change in F_c).

Cell Degradation - Explore methods to increase cell degradation resistance ($\$5.4\text{M}/1\%$ change in F_p (rad)).

Line Voltage - Perform a LCC trade study on the benefits of higher line voltages versus high voltage losses.

Years Between Overhaul - Explore the benefits of an add-on concept to offset degradation.

Mean Time Between Failures - Perform an in-depth study of the effects of reliability and maintenance on LCC.

Cell Costs - Perform an indepth study to model the relationship of cell cost versus cell efficiency, involving various manufacturing/maintenance scenarios. ($\$22\text{M}/\$$ of Cell Unit Cost).

6.5.2 Further Applications of the Model

The performance/cost model and techniques developed for this study can be modified, without complication, to support not only the specific technology studies recommended in 6.5.1, but a number of other areas:

- A. To determine an optimized combination of solar array parameters;
- B. To compare various solar array technologies (different cell and cover materials, cell/cover/coating combinations, etc.);
- C. To study various manufacturing scenarios;
- D. To study various missions: differing power requirements, orbits (all, LEO through GEO) and interplanetary;
- E. To study various reliabilities and maintenance scenarios;
- F. With more modification, the model can be expanded to determine technology vs. LCC for a total system such as the SSPS or any other space station concept. Thus, the total effect of subsystem technology may be quantified to include interfacing subsystems and other system elements such as DDT&E, Production, O&M, tracking, command and control, transportation, safety, and so forth.

7.0 REPORTING OF STUDY STATUS AND RESULTS

The following output has been provided over the course of the study:

- Monthly Progress Narratives (April, 1979 through March, 1980)
- Oral Presentations at:
 - Lewis Research Center, October 19, 1979
 - Lewis Research Center, February 20, 1980
 - NASA Headquarters, March 4, 1980
- Document: "Specification of Requirements, 500 kW Solar Array Subsystem", PRC, July 30, 1979 (Appendix A)
- Document: "Baseline 500 kW Solar Array Subsystem Definition", PRC July 30, 1979
- Document: "Solar Array Subsystem Study Final Report", PRC, Preliminary, March 20, 1980.

APPENDIX A

BASELINE 500 kW SOLAR ARRAY SUBSYSTEMS REQUIREMENTS
(SPECIFICATION)

SPECIFICATION

**BASELINE 500kW
SOLAR ARRAY SUBSYSTEMS
REQUIREMENTS**

Prepared For
**NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135**

MARCH 20, 1980
CONTRACT NAS3-21926

prc
PRC/SSC Solar Array Subsystems Project Office
7911 CHARLOTTE DRIVE • HUNTSVILLE, ALABAMA 35802

SPECIFICATION

BASELINE 500 kW
SOLAR ARRAY SUBSYSTEMS
REQUIREMENTS

CONTRACT NAS3-21926

JULY, 1979

MARCH, 1980 - UPDATE

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1.0 INTRODUCTION AND SCOPE

Under contract to NASA LeRC, a baseline Solar Array Subsystem (SAS) conceptual design is being developed for the purpose of determining the influence of varied technology on the life cycle costs of the subsystem and its interfacing elements.

This specification defines the requirements on the 500 kW (250 kW average) Solar Array Subsystem (SAS), a subsystem of the Space Support Platform System (SSPS). This is a top level subsystem specification. The relationship of this specification to the SSPS hierarchy of specifications is contained in Section 2.0.

2.0 APPLICABLE DOCUMENTS

- 2.1 The SSPS System specification tree is shown in Exhibit 2-1.
- 2.2 JSC 07700 Volume XIV, Space Shuttle Payload Accommodations, September 22, 1978
- 2.3 The applicability of other specifications, standards and other documents is TBD.

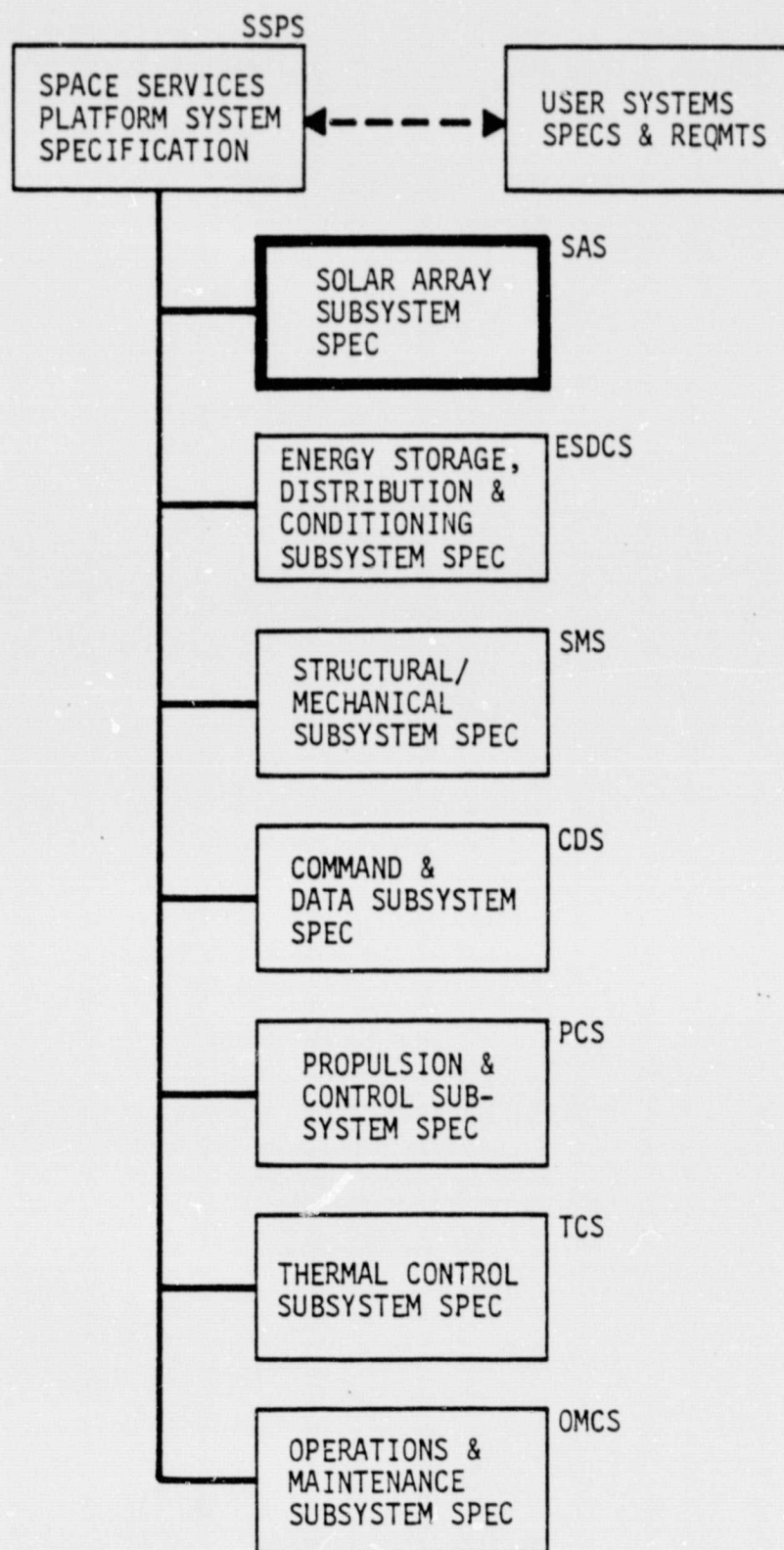


EXHIBIT 2-1 SSPS SPECIFICATION TREE

3.0 REQUIREMENTS

3.1 System Level Requirements

These requirements apply to the system level (the Space Service Platform System, SSPS) directly. The requirements on the Solar Array Subsystem derive from the system level requirements and are specified in Sections 3.2 through 3.5.

3.1.1 System Level Description

The purpose of the Space Services Platform System (SSPS) is to provide services to varied User Systems. The User Systems may be engaged in materials processing, astronomy, solar system and earth observation, life sciences, communications, or other operations. The User Systems may be secured to the platform or docked for servicing or short term operations.

The general configuration of the SSPS is shown in Exhibit 3-1. The subsystems of the SSPS, their functions and major interfaces are identified in Exhibit 3-2. The User Systems will interface with the SSPS subsystems as follows:

- | | |
|----------------------------|---|
| ● Electrical power | - ESDCS |
| ● Thermal control | - TCS |
| ● Structure | - SMS |
| ● Mechanical | - SMS |
| ● Instrumentation | - CDS |
| ● Operations/Maint. | - CDS |
| ● Gross Pointing Stability | - CDS (GUIDANCE)
PCS (SSPS ATTITUDE) |

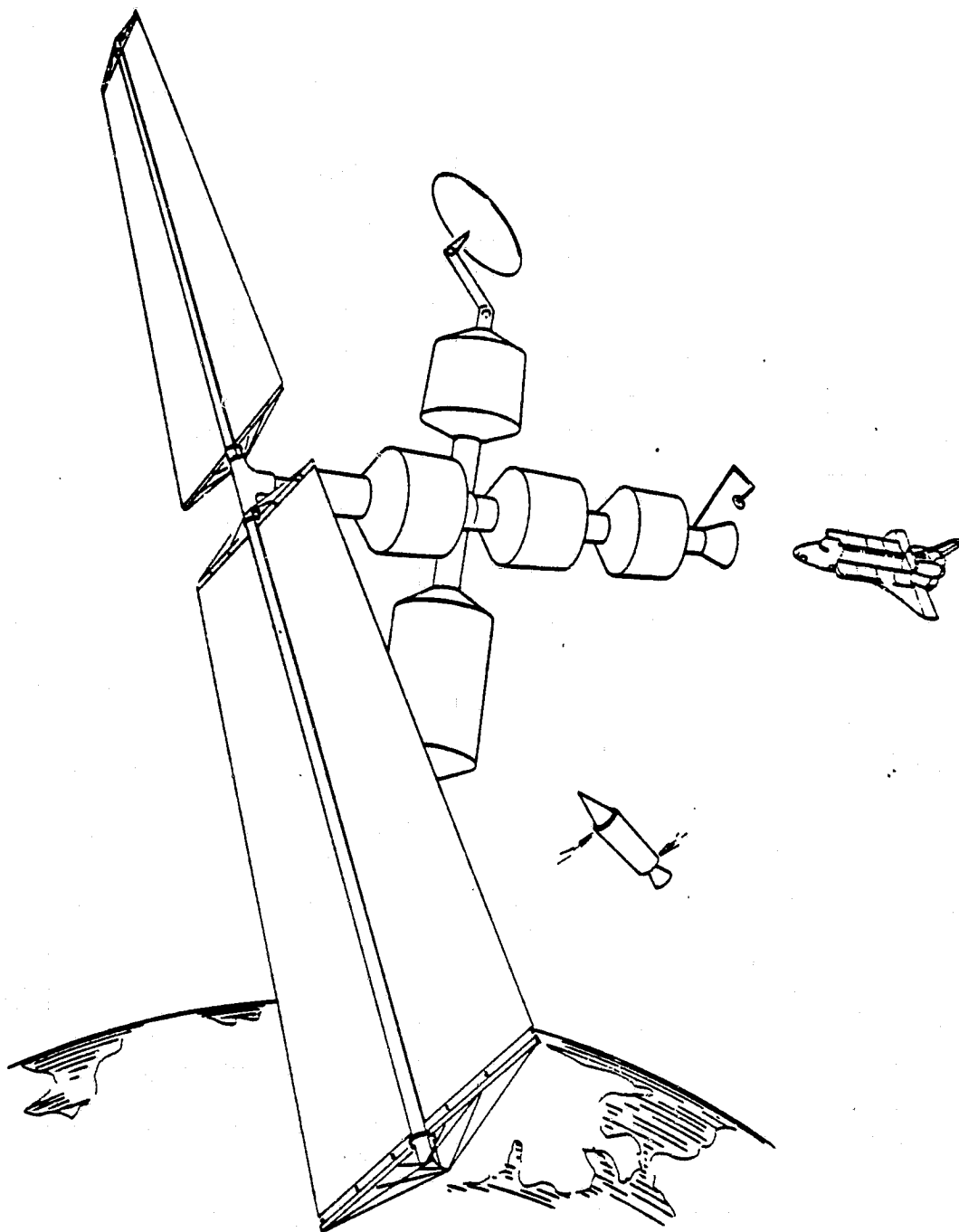


EXHIBIT 3-1 SSPS GENERAL CONFIGURATION

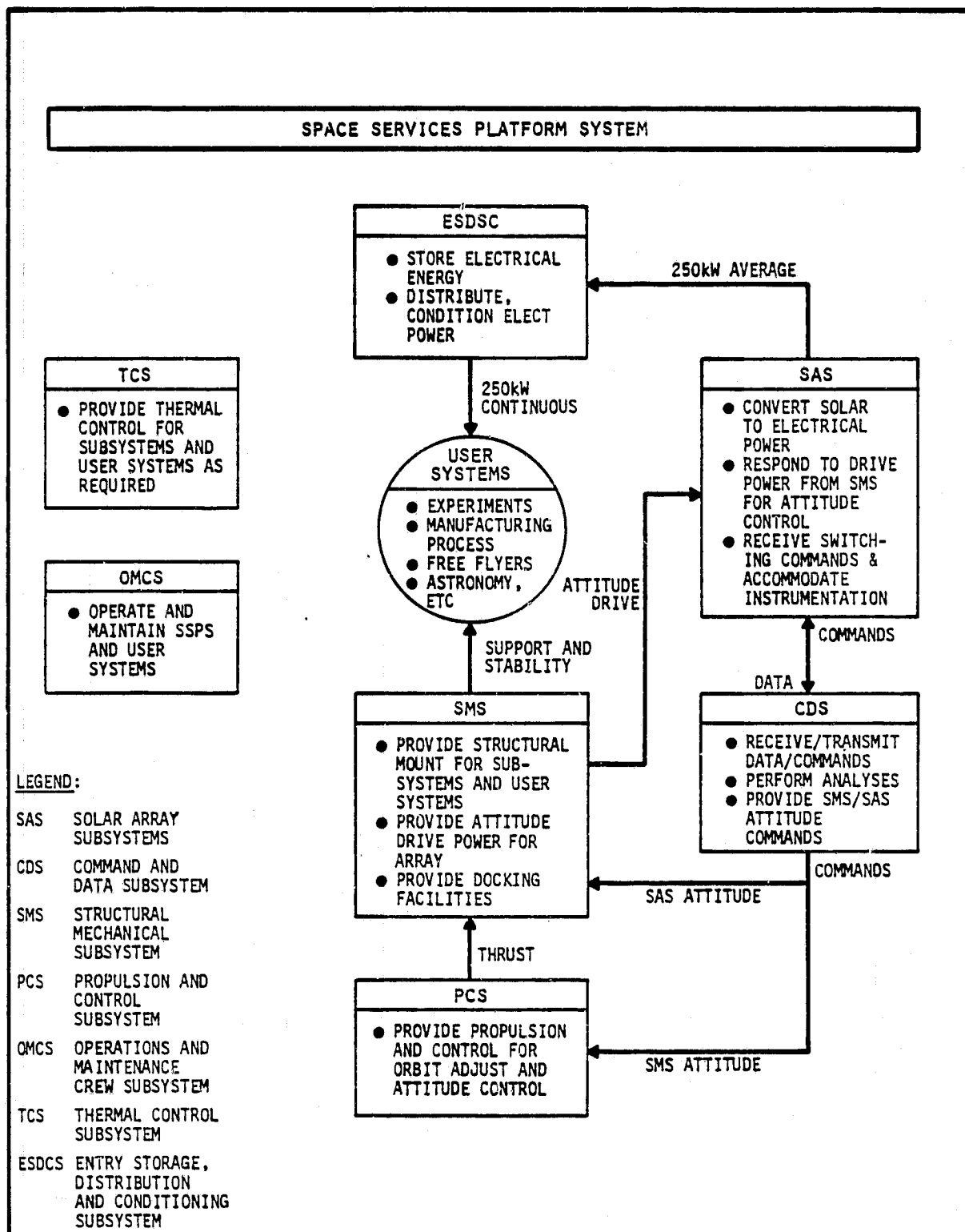


EXHIBIT 3-2 SSPS SUBSYSTEM FUNCTIONS AND INTERFACES

3.1.2 Mission Requirements

The following characteristics shall be used in the system and subsystem design.

3.1.2.1 General

- System operational 1985-1995
- State-of-art (1979) design
- Silicon solar cells; planar array (no concentration)
- Transportation to LEO: Shuttle

3.1.2.2 Orbit and Mission Parameters

- LEO circular, 444 km. Inclination 56° .
 - Orbital period: 87.3 minutes
 - Time in sun: 53.7 minutes, minimum
 - Time in eclipse: 33.6 minutes, maximum
 - Number of eclipses: 60,239-Ten Years

3.1.2.3 Electrical

- 250 kW continuous to loads, provided in 48, 24 or 16 individual power channels to the ESDCS subsystem at the slip ring interface (See Section 3.2.2.1)
- Provide this output from BOL to EOL
- Bus voltage for Users Systems to be:
 - 30VDC - small, experimental projects (20% of power)
 - 100-250 VDC-intermediate power projects and other SSPS subsystems (30% of power)
 - 1000 VDC - manufacturing, processes, large engine testing (50% of power)

3.2 Subsystem Performance and Interface Requirements and Constraints

These requirements apply to the Solar Array Subsystem (SAS) of the Space Services Platform System (SSPS); and have been derived from the system level requirements of Section 3.1.

3.2.1 Electrical Performance and Interface Requirements

3.2.1.1 SAS/ESDCS Electrical Interface

- The SAS shall provide electrical power to the ESDCS for energy storage, distribution and conditioning. The ESDCS will provide the electrical power/energy to the User Systems and other subsystems of the SSPS: SAS, CDS, SMS, TCS, PCS, and OMCS.
- The SAS shall provide electrical power to the ESDCS at the 2 axis drive/slip ring assembly output in accordance with the following table of options:

NUMBER OF POWER CHANNELS	MINIMUM POWER KW PER CHANNEL	MINIMUM VOLTAGE AT SLIP RING OUTPUT
48	10.0	180

- Total power output to the ESDCS shall be 480 kW peak EOL.

3.2.1.2 SAS Power Losses

The total power losses of the array shall not exceed 10%. These losses include:

- assembly factor
- diode drop
- wiring (cell, module panel inter-connections and main buses
- slip rings.

3.2.1.3 Degradation Compensation

The SAS shall be designed to achieve a constant electrical power output by varying the angle of incidence of the sun vector on the plane of the array over the 10 year period between overhauls.

3.2.1.4 Environmental Degradation

The SAS shall not exceed 50% degradation of BOL maximum power output (at slip-ring output) under the environment specified in Section 3.2.7.

3.2.2 Structural/Mechanical/Thermal Performance and Interface Requirements and Constraints

3.2.2.1 SAS Structural/Mechanical Performance

- The SAS shall be capable of withstanding orbit changes of altitude and inclination.
- Loads:
 - Perpendicular to plane of array: 0.01 G
 - Parallel to plane of array: 0.01 G
- The SAS array shall be held within ± 10 degrees of planar except during orbit maintenance thrusting.

3.2.2.2 SAS/SMS Interface

The SAS interfaces with the SMS shall be:

- Structural Attachment: The SMS shall provide the mounting assembly which secures the SAS to the SMS structure, at the SAS two axis drive/slip ring assembly.
- Attitude Control Drive Interface: The SMS shall provide the drive power required to implement SAS attitude commands received from the CDS. The interface shall be the two-axis drive assembly shaft at the SMS drive power source. Maximum angular velocity and acceleration required of the SMS drive power source shall be $\omega = 1^\circ/\text{sec}$, and $\dot{\omega} = 1^\circ/\text{sec}^2$ about the axes of pitch and roll, where pitch is motion about the SAS boom axis.

3.2.2.3 SAS/ESDCS Interface

- This mechanical interface shall be the electrical interconnects between the 2 axis drive/slip ring assembly output and the ESDCS.

3.2.2.4 SAS/PCS Interface

- Thruster induced loads shall be consistent with structural/mechanical requirements of Section 3.2.3.1
- Contaminant and charged particle constraints and tolerances shall be TBD.
- Thrusters will be located near the end-boom on the spar axis. These thrusters will be used for orbit maintenance thrusting.

3.2.2.5 SAS/TCS Interface

The SAS thermal control requirements and mechanical interfaces shall be: TBD

3.2.2.6 SAS/CDS Interface

- The SAS shall provide mechanical accommodations for command and data instruments which shall be components of the CDS. The CDS shall provide electrical power for command and data channels which interface with the SAS.
- The command and data channel list for SAS shall be: TBD.
- Communication requirements for space assembly, check-out, operations and maintenance activities will be (TBD).

3.2.2.7 SAS/OMCS Interface

- This interface is covered in Section 3.2.7

3.2.3 Transportation/Transportability

3.2.3.1 The SAS components shall be transportable to space by the Space Shuttle.

3.2.3.2 The SAS shall incorporate fold-up panels for space transportation.

3.2.3.3 The SAS design, as stowed for transportation shall meet the transportation environment specified in Section 3.2.7.

3.2.3.4 The maximum dimensions and total weight including containers, of a single-flight set of SAS components (blankets, structural components, electrical and mechanical interconnects, electrical buses, 2 axis drive/slip ring assembly) shall not exceed: 3.6 meters in diameter, 18 meters in cylindrical length, and 27,000 kg in weight. The CG limits shall be as specified in JSC 07700 Volume XIV.

3.2.4 Life and Reliability

- 3.2.4.1 The SAS shall be designed for a ten year operational period between blanket change-out with on-orbit scheduled and unscheduled maintenance performed by the OMCS. Over the ten year period, the electrical output shall not degrade due to the natural environment greater than 50% of BOL electrical power output.
- 3.2.4.2 The design shall be such that failures will be non-proliferating.
- 3.2.4.3 Reliability specifications shall be subject to life cycle cost trade analyses.
- 3.2.4.4 The design shall provide that the number of panels whose output is $\leq 92\% P_0$ (EOL) shall not exceed 5% of the array area at any one time over the 10 year blanket life.
- 3.2.4.5 The number of panels changed out for failure shall not exceed 12% of the array area over the 10 year blanket life.
- 3.2.4.6 Storage life is TBD.

3.2.5 Safety

The SAS design and procedures for all phases of production, earth and space integration, transportation and O&M, shall assure the chance of serious injury or death over a 10 year period is less than one in 10^7 man-hours.

3.2.6 Maintenance/Maintainability

3.2.6.1 Logistics and Spares

The normal supply mode shall be a set of on-hand (in space) spares and materials sufficient for ten year's operation. The spares set shall be delivered by the Space Shuttle.

The OMCS personnel crew shall be changed out every three months. Transport mode shall be Space Shuttle.

3.2.6.2 Overhaul

The SAS shall be designed for array blanket change-out every 10 years.

3.2.6.3 Maintenance

- The SAS blanket shall be modularized for panel removal and replacement with a serviceable spare.
- In place (on-array) repair shall be limited to the panel level or higher.
- In-space, shop repair of panels at panel level or lower shall be: TBD
- Panels shall be considered failed at 90% of P_0 (EOL), and shall be changed out.
- The SAS design shall enable repair/replacement (and checkout) time of 24 manhours per modular panel.
- The SAS design shall permit automatic fault isolation to the failed panel(s).
- The Solar Array Subsystem (SAS) shall be capable of assembly and checkout in space. Assembly will include hook-up and attachment to the (SMS) and other subsystems of the SSPS system.

3.2.7 Environment

3.2.7.1 Natural Environment

The design shall meet the requirements of this specification within the natural environment (worst case 20 year prognosis) of the earth orbit range of: 300 to 1900 km, all inclinations. This environment shall include effects due to U.V. radiation, solar flares, trapped radiation and micrometeorites.

3.2.7.2 Transportation Induced

- Earth surface/air transport:
TBD
- Launch and ascent to LEO
 - Axial acceleration of 5g
 - Lateral acceleration of 0.5g
 - Decaying sinusoidally of 7g at 16 Hz
 - Sinusoidal vibration (three mutually perpendicular directions) ± 1 g peak from 2 to 40 Hz
 - Random vibration (gaussian amplitude distribution) $0.1 \text{ g}^2/\text{Hz}$ from 10 to 60 Hz, $0.4 \text{ g}^2/\text{Hz}$ from 60 to 2,000 Hz
 - Acoustic noise (decibels re 0.0002 microbar) up to 150 db (3 minutes duration) 45 to 11,200 Hz
- Ascent Venting Profile - TBD

3.2.7.3 Operational Induced

- The induced operational environments shall be as specified in Section 3.2 interface requirements.
- Contaminants - TBD

3.3 Design & Construction

3.3.1 Materials Properties

3.3.1.1 Materials Compatibility

TBD

3.3.1.2 Outgassing

TBD

3.3.1.3 Insulation Resistance

TBD

3.3.1.4 Voltage Breakdown

TBD

3.3.1.5 Contaminants Sources

TBD

3.4 Verification Requirements

The requirements of this specification shall be as specified in Section 4.0, verification. (Section 4.0 is TBD)

3.5 Personnel & Training Requirements

TBD

APPENDIX B

LIFE CYCLE COST DATA

INDIRECT EXPENSES

PRODUCTION PHASE

- Fringe Rate = 32% and includes all fringe benefits.
- Overhead Rate = 125% and includes:
 - Utilities and telephones
 - Depreciation of facilities and capital equipment
 - Maintenance and operations of facilities and equipment
 - Indirect Labor - supervisors, foremen, clerks, typists, secretaries
 - Indirect Labor Fringe Benefits
- Other Direct Charges = 10% and includes computer supplies and expense, travel expense and direct rental equipment expense.
- General and Administrative Rate = 15% and includes: Finance, contracts, personnel, legal services, public relations, and a manager and their associated costs of doing business, taxes and insurance.

OPERATIONS AND MAINTENANCE PHASE

- Fringe Rate = 32% and includes all fringe benefits.
- Overhead Rate = 50% and includes program management, secretarial support and supervision, and use of a test facility as required.
- Other Direct Charges = 10% and includes computer supplies and expense, travel expense and direct rental equipment expense.
- General and Administrative Rate = 15% and includes finance, procurement, contract, legal services, public relations, and a general manager and their associated costs of doing business, taxes and insurance.

**LIFE CYCLE COST - DDT&E PHASE
(1980 DOLLARS IN MILLIONS)**

CDDT&E = .35 CPROD = 153.9

**LIFE CYCLE COST - PRODUCTION PHASE
(1980 DOLLARS IN MILLIONS)**

SAS MANUFACTURING COST

LABOR

DIRECT LABOR	12.8
FRINGES	4.0
OVERHEAD	16.0
ODC	<u>1.2</u>
SUBTOTAL	34.0

NON-LABOR

MATERIALS	99.3
MATERIALS BURDEN	9.9
EQUIPMENT	141.5
EQUIPMENT MAINTENANCE	9.9
SPECIAL EQUIPMENT	1.0
SURFACE TRANSPORTATION	<u>0.1</u>
SUBTOTAL	261.7

TOTAL MANUFACTURING COST

LABOR	34.0
NON-LABOR	<u>261.7</u>
SUBTOTAL	295.7
PROJECT MANAGEMENT	17.2
SE	<u>14.2</u>
SUBTOTAL	327.1
G&A	<u>49.0</u>
TOTAL \$	376.1

NASA COST

SHUTTLE TRANSPORTATION	63.0
SPACE ASSEMBLY & CHECKOUT	<u>.8</u>
TOTAL	63.8

TOTAL PRODUCTION PHASE COST

MANUFACTURING	376.1
NASA	<u>63.8</u>
TOTAL	439.9

**LIFE CYCLE COST - O&M PHASE
(1980 DOLLARS IN MILLIONS)**

CONTRACTOR COST

DIRECT LABOR	\$	.4
FRINGES		.1
OVERHEAD		.2
ODC		.1
		<hr/>
SUBTOTAL		.8
G&A		.1
		<hr/>
TOTAL CONTRACTOR'S COST		.9

NASA INCURRED COST

TRAIN O&M CREW	2.5
TRANSPORT CREW	146.3
PERFORM MAINTENANCE	11.0
	<hr/>
TOTAL NASA INCURRED COST	159.8

TOTAL COST OF O&M PHASE

CONTRACTOR'S COST	.9
NASA COST	159.8
	<hr/>
	160.7

**TOTAL LIFE CYCLE COST SUMMARY
(1980 DOLLARS IN MILLIONS)**

DDT&E	153.9
-------	-------

PRODUCTION	439.9
------------	-------

O&M	<u>160.7</u>
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TOTAL LIFE CYCLE COST	754.5
-----------------------	-------

TOP LEVEL COST RELATIONSHIP SOURCES

- AEROSPACE CORPORATION ADVANCED SPACE POWER REQUIREMENTS & TECHNIQUES
 - HISTORICAL AND PROJECTED DATA
- MSFC COMMON SOLAR ARRAY COST ESTIMATE SUMMARY:
 - CELL, CELL/COVER ASSEMBLY, MODULE ASSEMBLY
- PRC COST ESTIMATING TECHNIQUES FOR MISSION SYSTEM INTEGRATION AND TEST ELEMENTS OF FUTURE SPACE MISSIONS
 - PROJECT MANAGEMENT AND SE
- NASA REPORT TO THE SPECIAL PANEL FOR SPACE EVALUATION:
 - \$300/WATT
 - DDT&E = 0.35 PRODUCTION COST
- JSC STS REIMBURSEMENT GUIDE:
 - \$31 M/DEDICATED FLIGHT TO 444 km 56° INCLINATION.
- MSFC/JSC TELECONS
 - ASTRONAUT LABOR OF \$250 PER MAN-HOUR INCLUDES:
OVERHEAD, TRAINING, LIFE SUPPORT, DIRECT LABOR
 - SPACE MANEUVERING PLATFORM COST
- LABOR, MATERIALS, PROCESS AND EQUIPMENT SOURCES:
 - BOEING
 - LOCKHEED
 - HUGHES
 - TRW
 - BALL BROTHERS
 - SPECTROLAB
 - OCLI
 - ASTRO RESEARCH
 - HEWLETT-PACKARD
 - 3M
 - REYNOLDS
 - UAL
 - OTHER

APPENDIX C

SOLAR ARRAY PERFORMANCE & COST MODEL PROGRAM

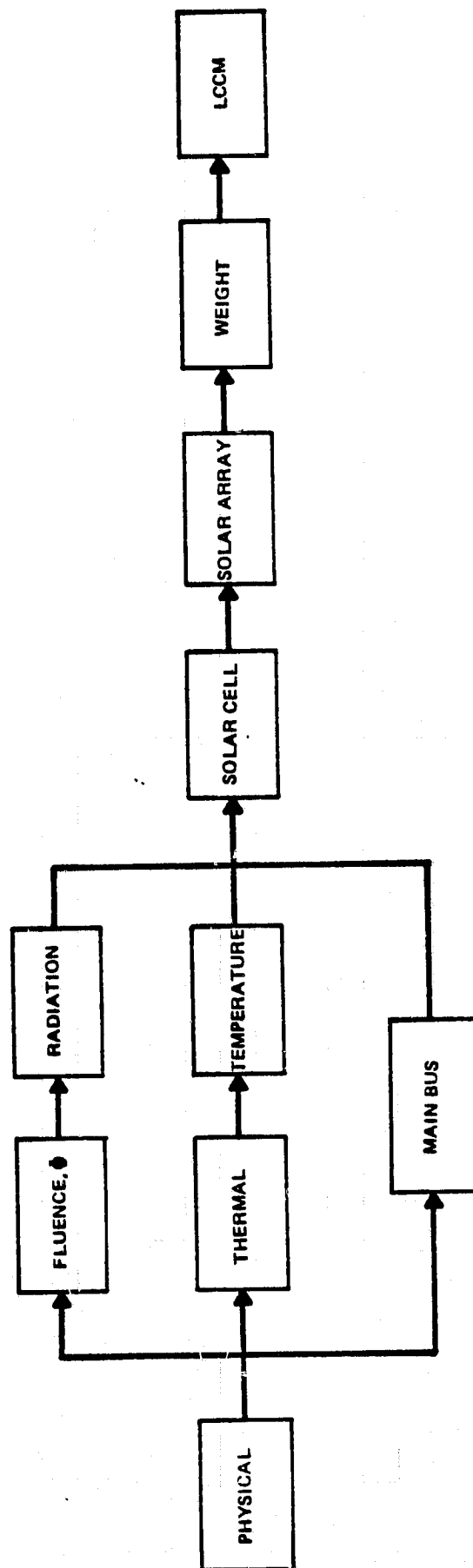


EXHIBIT C-1 BASIC INTERRELATIONSHIP OF SACPM PROGRAM SECTIONS

1.0 INTRODUCTION

The program for the Solar Array Performance and Cost Model (SACPM) is written for the TI-59 programmable calculator with a Master Library module. The total program consists of 4649 steps which are divided into 10 subroutines as indicated in the table below:

<u>PROGRAM SUBROUTINE</u>	<u>PROGRAM STEPS</u>	<u>DATA BASE REGISTERS</u>	<u>PROGRAM BANKS</u>	<u>DATA BASE BANKS</u>	<u>TOTAL BANKS</u>	<u>TOTAL # CARDS</u>
1. Physical	716		3		3	2
2. Fluence, ϕ	421	15	2	1	3	2
3. Radiation	344	21	2	1	3	2
4. Thermal	478		2		2	1
5. Temperature	636		3		3	2
6. Main Bus	267		2		2	1
7. Solar Cell	470	30	2	1	3	2
8. Solar Array	478	16	2	1	3	2
9. Weight	461		2		2	1
10. LCCM	378	26	2	1	3	2
	<hr/> 4649	<hr/> 108	<hr/> 22	<hr/> 5	<hr/> 27	<hr/> 17

1.1 Program Description

The SACPM program models the cost-technology relationships of a silicon planar 500 kW (250 kW continuous) space solar array for a LEO Space Platform mission. The modeling approach, generally, is to

- define the solar cell, cover, substrate and cell interconnect circuitry (module cross section)
- determine the value of the solar array factors which affect performance and apply to the BOL cell/cover assembly to determine the EOL per cell array performance.
- determine number of cell/cover assemblies required for baseline orbit and load power/energy requirements

- determine total array area, dimensions and structural requirements (array configuration)
- determine array weight breakdown and totals
- determine life cycle cost.

Exhibit C-1 is a block diagram which shows the basic interrelationship of the SACPM program subroutines. The following paragraphs contain a description of the program subroutines.

1.1.1 Physical

Given the inputs listed below, the physical subroutine of the SACPM program provides the outputs indicated. The exhibit numbers refer to exhibits in the main body of this report which contain the information described.

<u>INPUTS</u>	<u>OUTPUT(S)</u>	<u>EXHIBIT(S)</u>
All Length	Cell Area Substrate Area Packing Factor	5.4
Cell Width		
L Distance Between Cells		
W Distance Between Cells		
Material Thickness	Mass/Weight Shielding Thickness	5.4
Material Density		
Material Area		5.5
Material Mass	Thermal Mass	5.8
Material Heat Capacity		

1.1.2 Fluence, ϕ

The fluence subroutine of the SACPM program computes the equivalent radiation fluence that the solar cell "sees". The total back and front shielding thickness previously computed in the physical subroutine section (Exhibit 5.5) and the orbit altitude provide the inputs for this subroutine section. The fluence environment model is graphically depicted in Exhibit 5-6 of the main body of this report. The front and back fluences are summed to determine the total equivalent fluence.

1.1.3 Radiation

Given the fluence subroutine output described above and the solar cell thickness as inputs to the radiation subroutine, the solar cell radiation performance factors are calculated for power and voltage. The radiation factor modeling for power and voltage is graphically depicted in Exhibit 5-7 of the main body of this report.

1.1.4 Thermal

The thermal subroutine performs the calculations shown in Exhibit 5-9 of the main body of the report. The outputs of this subroutine are inputs to the temperature subroutine.

1.1.5 Temperature

The temperature subroutine uses as inputs the thermal mass profile in Exhibit 5.8 and the thermal calculations in Exhibit 5-9 of the main body of this report. The temperature subroutine calculates temperature profiles of array temperature versus time in orbit, and array average illumination and average temperature during the illuminated portion of the array orbit. Examples of these calculations are contained in Appendix D of this report.

1.1.6 Main Bus

The main bus subroutine provides the input parameters for the following equation:

$$\frac{L}{A} = \sqrt{\frac{P_D \times C_D \times \Sigma L^2}{N \times I^2 \times p}}$$

The equation and its parameters, together with its use in determining the performance factors for the main bus conductor, are described in paragraph 5.2.1.8.5 of the body of this main report.

1.1.7 Solar Cell

The solar cell subroutine performs four functions in conjunction with the solar array parameters as described in paragraph 5.2.1 of the main body of this report. The first function is computation of the EOL maximum power per cell

using the basic equation:

$$EOL P_{mp} (W/m^2) = \left[\left(\eta_{BOL} \times \prod_{i=1}^{11} F_{p_i} \right) \times \left(S' \times \prod_{j=1}^2 F_{p_j} \right) \times PF \right] \times A_s$$

The equation and its parameters are discussed in the main body of this report (paragraph 5.2.1).

The second function is calculation of the temperature derating factor using the temperature curves in Exhibit 5-10 of the report's main body. It should be noted that because of the influence of the average illumination, the calculation for the temperature derating power factor is a "two-dimensional" process.

The third function is calculation of the main bus conductor performance factor. This is accomplished as described in paragraph 5.2.1.8.5 of the main body of this report.

The fourth function is calculation of the EOL maximum power and maximum voltage per cell, which are used for array sizing in the solar array subroutine.

1.1.8 Solar Array

The solar array subroutine uses the EOL maximum power and maximum voltage per cell to determine the array configuration and performance. The outputs are the information depicted in Exhibits 2-5, 2-6, 2-7 and 2-18 of the main body of this report.

1.1.9 Weight

The weight subroutine provides the information shown in Exhibits 2-19 and 2-20 of this report, with the exception of array area, which is calculated in the solar array subroutine above.

1.1.10 Life Cycle Cost Model (LCCM)

The block diagram of the LCCM subroutine is shown in Exhibit 4-1 of the main body of this report. The inputs and factors used are summarized in Exhibits 4-4 and 4-5. The output data is summarized in Exhibits 4-3, 4-5, 4-6, and 4-7. A discussion of the LCCM is included in Section 4 and Appendix B of this report.

1.2 Use of SACPM Program

The procedure for using the SACPM program subroutines is given in the following paragraphs. A sample output tape is described in Appendix E.

(NOTE: Once the initial partition -- 729.19 -- is set, the program will automatically set the partition for the remaining subroutines if all ten subroutines are used in the sequence listed on the following pages.)

1.2.1 Physical Subroutine (729.19)

PROCEDURE

1. Enter cell length
2. Enter distance between cells in L direction
3. Enter cell width
4. Enter distance between cells in W direction
5. Calculate/print area parameters

L = Cell length
 ΔL = Distance in L direction
W = Cell width
 ΔW = Distance in W direction
 A_C = Cell area
 A_S = Per-cell substrate area
PF = Packing factor

6. Enter material thickness
7. Enter material density
8. Enter material ID # and calculate physical parameters

T = Material thickness
D = Material density
M = Material Mass
A = Material Area
W = Material Weight

(NOTE: Press E to insert material; E' to delete material from data base - card bank #4)

REMARKS

PRINT

DISPLAY

PRESS

ENTER

L

A'

ΔL

B'

W

C'

ΔW

D'

-

A

L

ΔL

W

ΔW

A_C

A_S

PF

T

C

D

D

-

E/E'

ID#

T

D

M

A

W

PROCEDURE

REMARKS

PRINT

DISPLAY

PRESS

ENTER

T = Material thickness
D = Material density
T' = Shielding thickness
M' = Per cell mass (includes packing factor)

9. Enter material heat

capacity profile and

calculate thermal mass

(NOTE: Repeat step 9 for

9 values of C_p - See

Exhibit 5-8)

C_p = Material heat capacity
MCP = Thermal mass

C_p
MCP
↓
 C_p
MCP

-

R/S

C_p

Steps 6-9 are repeated for each material. The material ID #'s to be used are as follows:

- 0 - Cover
- 0.1 - Cell/cover adhesive
- 0.X - Cover coating (if applicable)
- 1 - Cell
- 1.X - Cell coating (if applicable)
- 2 - Cell laydown adhesive (if applicable)
- 3.X - Substrate materials

PROCEDURE

ENTER PRESS DISPLAY PRINT REMARKS

10. Print summation of array parameters

- B - Σ+

(NOTE: The array component ID #'s are as follows:

Per cell area parameters

- 1 - Cell/Cover assembly
- 2 - Cell/Substrate adhesive (if applicable)
- 3 - Substrate
- 5 - Module assembly (includes packing factor)

Parameters for array components e.g., cell/cover assembly, substrate, module

ID#
T
D
M
A
W

(NOTE: The radiation shielding ID #'s are as follows:

- 7 - Front shielding
- 8 - Back shielding

Parameters for radiation shielding e.g., front and back

ID#
T
D
T'

R₂₁ - R₂₉ are parameters for thermal mass profile

R₂₁
+
R₂₉

1.2.2 Use of Fluence Subroutine (719.29)

<u>PROCEDURE</u>	<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
1. Enter orbit altitude (NOTE: Enter KM at A; NM at A')	Alt	A/A'	KM		
Step 1 changes partition from 719.29 to 479.59					
2. Enter lifetime of array (2.5, 5 years) (NOTE: This step is not required if array lifetime = baseline array lifetime = 10 years.)	Yrs	B	Yrs		
3. Calculate/print total fluence (NOTE: This step uses the front and back shielding thicknesses calculated (and stored) during the physical subroutine.)	-	C	-	KM YRS T' F T' F ΣF	KM = Altitude in KM YRS = Array lifetime T' = Shielding thickness F = Fluence (Prints fluence for both front and back shielding thickness) ΣF = Total fluence

<u>PROCEDURE</u>	<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
3a. Calculate/print fluence for manually entered shielding thickness parameter (NOTE: This function calculates fluence for any input value of shielding thickness (1 mil = $T' < 18$ mils). It is not intended for use in conjunction with outputs from the subroutine.)	T'	D/D'	-	KM YRS T' F	D' input does not print KM, YRS (KM, YRS entered in steps 1 and 2 respectively)
3b. Calculate/print fluence profile (T' = 1, 2, 3...18 mils) (NOTE: This function provides a fluence profile for values of T' from 1 mil to 18 mils in steps of 1 mil)	-	E	-	KM YRS T' F	Entered in step 1 Entered in step 2 Repeats for T' = 1, 2, 3 ...18

1.2.3 Use of Radiation Subroutine (479.59)

- Enter cell thickness t B t
(NOTE: This step is not required if cell thickness = baseline cell thickness = 8 mil.)

<u>PROCEDURE</u>	<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
2. Calculate/print solar cell performance factors	-	C	-	"RAD"	
				CT	CT = Cell thickness
				ΣF	ΣF = Total fluence
				FP	FP = Power performance factor
				FV	FV = Voltage performance factor
2a. Enter fluence and calculate/print solar cell performance factors	ΣF	D/D'	-	"RAD"	D input does not print "RAD" and CT (CT entered in step 1)
(NOTE: This function calculates the solar cell power and voltage performance factors for any input value of fluence ($1 \leq \Sigma F \leq 1000$) - see Exhibit 5-7. The function is not intended use in conjunction with outputs from the fluence subroutine.)				CT	
				ΣF	
				FP	
				FV	
2b. Calculate/print radiation performance factor profiles ($\Sigma F = 1, 10, 20, 40, 100, 200, 400, 1000$)	-	E	-	"RAD"	
				CT	Entered in step 1

PROCEDURE

(NOTE: This function provides a fluence profile for values of fluence from 1 to 1000 (10^3 to 10^{16}) in the steps indicated above.)

Repeats for $\Sigma F = 1, 10, 20, 40, 100, 200, 400, 1000$

ENTER PRESS DISPLAY PRINT

ΣF FP FV

REMARKS

1.2.4 Use of Thermal Subroutine (479.59)

(NOTE: To perform entire subroutine operation using only baseline numbers, press SBR SUM.)

1. Calculate/print orbit

parameters

(NOTE: To enter orbit altitude if not entered previously during fluence subroutine, enter alt. in NM and press SBR INV or in KM and press SBR X/T.)

"O" KM θ a b

O = ID #
KM = Orbit altitude
 θ = Reference angle (used in calculations)
a = Total orbit period
b = Period of illumination

2. Enter α cover α_1 B α_1

3. Enter α substrate α_2 C α_2

<u>PROCEDURE</u>	<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
4. Calculate/print α_F array front (NOTE: To enter packing factor if not entered previously during physical subroutine, enter PF and press SBR lnx.)	-	A'	-	"1" α_1 PF α_2 (1-PF) α_F	1 = ID # α_1 = α cover PF = Packing factor α_2 = α substrate α_F = Composite absorptivity for front of array
5. Enter estimated BOL solar cell power loss factor	\overline{F}_p	B	\overline{F}_p		
6. Enter solar cell BOL efficiency	η_{BOL}	C	η_{BOL}		
7. Calculate/print array electrical power density	-	B'	-	"2" PF \overline{F}_p η_{BOL} q_E	2 = ID # PF = Packing factor \overline{F}_p = EOL loss factor η_{BOL} = BOL efficiency q_E = Array electrical power density (W/m ²)

<u>PROCEDURE</u>	<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
8. Enter α back and calculate/print $\alpha_{SF} = \alpha - \alpha_E$	α_B	C'	-	"3"	3 = ID # $\alpha_B = \alpha$ back $\alpha_{SF} = \text{effective } \alpha \text{ front}$
9. Enter ϵ cover	ϵ_1	B	ϵ_1		
10. Enter ϵ substrate	ϵ_2	C	ϵ_2		
11. Calculate/print ϵ_F array front	-	D'	-	"4"	4 = ID # $\epsilon_1 = \epsilon$ cover PF = Packing factor $\epsilon_2 = \epsilon$ substrate $\epsilon_F = \text{Composite emissivity for front of array}$
(NOTE: To perform steps 12 thru 17 using only baseline numbers, enter $\epsilon_B = .8$ and press SBR RCL.)					
12. Enter α space platform	α_{SP}	SBR lnx	α_{SP}		
13. Enter $\cos \Gamma_4$ ($\Gamma_4 = \text{"look angle" from array to space platform}$)	$\cos \Gamma_4$	B	$\cos \Gamma_4$		
14. Enter $\cos \Gamma_5$ ($\Gamma_5 = \text{"look angle" from space platform to array}$)	$\cos \Gamma_5$	C	$\cos \Gamma_5$		

PROCEDURE

ENTER PRESS DISPLAY PRINT REMARKS

15. Enter space platform

temperature

$^{\circ}\text{C}$ $^{\circ}\text{C}$

16. Enter back emissivity
adjustment factor (if
≠ .75)

f SBR f
CE

(NOTE: The adjustment
factor estimates the effect
of solar cell interconnects
on array back emissivity.)

17. Enter ϵ array back material
and calculate/print thermal
parameters

ϵ_B	E	-	"5" = ID #
ϵ_B			$\epsilon_B = \epsilon$ array back material
f			f = Back emissivity adjustment factor
ϵ_B			ϵ_B = Composite emissivity for back of array
α_{SP}			α_{SP} = Absorptivity of thermal energy from space platform
$\cos \Gamma_4$			Γ_4 = "look angle" from array to space platform
$\cos \Gamma_5$			Γ_5 = "look angle" from space platform to array

<u>PROCEDURE</u>	<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
17a. Enter ϵ array back material and calculate/print thermal parameters	ϵ_B	E'	-	q_{SP}	q_{SP} = Thermal energy absorbed from space platform
(NOTE: Step 17a is an alternate to steps 12 thru 17 for $q_{SP} = .025$ and $^{\circ}C = 50$. If the adjustment factor $f \neq .75$, step 16 must be performed prior to performing step 17a.				$^{\circ}C$	$^{\circ}C$ = Space platform temperature
				R8 ↓ R29	R ₈ thru R ₂₉ - Various parameters used for calculation of array temperature profile using temperature subroutine.

17a. Enter ϵ array back

material and calculate/print thermal parameters

(NOTE: Step 17a is an

alternate to steps 12 thru

17 for $q_{SP} = .025$ and $^{\circ}C = 50$.

If the adjustment factor

$f \neq .75$, step 16 must be

performed prior to performing

step 17a.

(Same as step 17 except α_{SP} ,
 $\cos \Gamma_4$ and $\cos \Gamma_5$ are
omitted)

1.2.2.5 Use of Temperature Subroutine (639.39)

See Appendix D

(NOTE: Use of thermal subroutine prior to use of this subroutine will properly set partition for this subroutine.

PROCEDURE

(NOTE: To start temperature profile at beginning of orbit eclipse period, enter period of illumination b at A before performing the following steps.)

1. Enter average illumination

2. Enter temperature

(NOTE: Enter °K at C;
°C at C'.)

3. Calculate/print temperature profile

(NOTE: Pressing E starts profile at the beginning of the orbit illumination period. Pressing E' starts profile at the end of the orbit illumination period (beginning of orbit eclipse period.)

<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
(b)	(A)	(b)		
\bar{S}	B	\bar{S}		(NOTE: t, S', T are printed respectively for orbit period of illumination. t, T only are printed respectively for orbit period of eclipse.)
T	C/C'	T		
-	E/E'	-	t	t = time in Orbit period
			S'	S' = effective illumination
			T	(includes albedo effect) at time t in orbit
			T	T = Array temperature at time t in orbit
		\bar{S}'	\bar{S}'	\bar{S}' = Average effective illumination for total orbit period of illumination
		\bar{T}	\bar{T}	\bar{T} = Average array temperature for total orbit period of illumination
			t	
			T	

<u>PROCEDURE</u>	<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
4. Print data base	-	D	-	R ₈ + R ₂₉	R ₈ thru R ₉ is data base for temperature subroutine.
1.2.6 Use of Main Bus Subroutine (639.39)					
(NOTE: To perform entire subroutine operation using only <u>baseline numbers</u> , press SBR SUM. This also stores baselines values for solar cell efficiency and maximum voltage.))					
1. Change partition	-	A	0		Changes partition to 479.59
(NOTE: Use step 2 if main bus subroutine is used in conjunction with parameters calculated by physical subroutine. To enter new numbers, use steps 2a and 26.)					
2. Compute/store per-cell module area and weight	-	B	-		Uses as inputs, area and weight parameters calculated by physical subroutine.
2a. Store per-cell module area	A _S	A'	A _S		A _S = per-cell module area

PROCEDURE

ENTER PRESS DISPLAY PRINT REMARKS

2b. Store per-cell module weight

W_S B' W_S W_S = per-cell module weight

3. Store density of main bus conductor

C_D C' C_D C_D = conductor density

4. Store resistivity of main bus conductor

P C P P = conductor resistivity

(NOTE: Use step 5 if main bus subroutine is used in conjunction with parameters calculated by solar array subroutine. To enter new numbers, use steps 5a - 5c.)

5. Compute/print ΣL^2

$-$ D^1 $-$ L_1^2
 $(L_1)^2$ $+$ L_N^2
 $(L_N)^2$ ΣL^2 = Sum of squares of all bus conductor lengths

5a. Enter number of channels for total array

n_C SBR n_C n_C = # channels/array

CE

<u>PROCEDURE</u>	<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
5b. Enter number of panels/ channel	n_p	SBR lnx	n_p		n_p = # of panels/channel
5c. Enter length folded blanket and compute/ store ΣL^2	w_p	D	ΣL^2	(Same as for step 5)	w_p = width of panel
(NOTE: Use only step 6 if main bus subroutine is used in conjunction with parameters calcu- lated by solar array subroutine. To enter new number, use step 5a before step 6.)					
6. Compute/store number of conductor pairs/blanket	-	E	N		N = Number of conductor pairs/ blanket
(NOTE: Use only step 7 if main bus subroutine is used in conjunction with parameters calcu- lated by solar array subroutine. To enter new number, use steps 5b and 7a before step 7.)					

PROCEDURE

ENTER PRESS DISPLAY PRINT REMARKS

7. Enter number of cells in series per 1/2-module and compute/store total number of cells in series per channel

S_M	E'	S_C	S_M = Number of cells in series/ 1/2-module
			S_C = Number of cells in series/ channel

- 7a. Enter number of 1/2 modules/panel

N_M	SBR	N_M	N_M = # of panels/channel
	INV		

8. Print stored parameters

-	SBR	-	$R_8 - R_{29}$ contain parameters for use as inputs to solar cell subroutine.
	RCL	R_8 ↓ R_{29}	

1.2.7 Use of Solar Cell Subroutine (479.59)

1. Store solar cell BOL efficiency

η_{BOL}	D'	η_{BOL}	η_{BOL} = BOL solar cell efficiency
--------------	------	--------------	--

2. Store solar cell BOL maximum voltage

$V_{mp(BOL)}$	E'	$V_{mp(BOL)}$	$V_{mp(BOL)}$ = BOL solar cell maximum voltage
---------------	------	---------------	---

<u>PROCEDURE</u>	<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
3. Store average illumination during orbit period from temperature subroutines	\bar{S}'	A	\bar{S}'		\bar{S}' = average illumination during orbit period from temperature subroutine
4. Store average temperature during orbit period from temperature subroutine (NOTE: Step 5 must be performed twice. Once for EOL cell efficiency at <u>minimum</u> average illumination/temperature and once for EOL maximum voltage at <u>maximum</u> average illumination/temperature.)	\bar{T}	B	\bar{T}		\bar{T} = average temperature during orbit period from temperature subroutine
5. Compute/print solar cell EOL efficiency/maximum voltage (NOTE: To initiate computation press C. Then compare displayed $F_p(V_{mb})^*$ with printed $F_p(V_{mb})^*$. If \neq , recompute by pressing E or by entering the $F_p(V_{mb})^*$ value and pressing D.)	- $F_p(V)$	C + D or E	$F_p(V_{mb})^*$	η_{EOL} \bar{S}' F_G F_τ \bar{S}' \bar{T} \bar{T}_{op}	η_{EOL} = EOL solar cell efficiency \bar{S}' = average temperature during orbit period from temperature subroutine F_G = glassing factor F_τ = cell cover degradation factor \bar{S}'_{EOL} = EOL effective illumination

<u>PROCEDURE</u>	<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
				$\overline{T}(\text{Top})$	\overline{T} = average temperature during orbit period from temperature subroutine
				Fp(A)	
				Fp(V _D)	\overline{T}_{op} = EOL average operating temperature
				Fp(V _{SC})	
				Fp(V _{MM})	Fp() = solar cell power performance factors (see below for specific factor)
				Fp(V _{PP})	
				Fp(V _{mb})*	
				Fp(V _{sr})	Fv() = solar cell voltage performance factors (see below for specific factor)
				Fp(Leak)	
				Fp(tc)	
				Fp(Rad)	A = assembly factor
				Fp(II)	V _D = blocking diode voltage factor
				Fv(\overline{T}_{op})	V _{SC} = solar cell electrical interconnect voltage factor
				Fv(A)	V _{MM} = module/module electrical interconnect voltage factor
				Fv(V _D)	V _{PP} = panel/panel electrical interconnect voltage factor
				Fv(V _{SC})	V _{mb} = main bus conductor voltage factor
				Fv(V _{MM})	V _{sr} = slip ring conductor voltage factor
				Fv(V _{PP})	
				Fv(V _{mb})	
				Fv(V _{sr})	
				Fv(Leak)	
				Fv(tc)	Leak = High voltage leakage factor

<u>PROCEDURE</u>	<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
(NOTE: To change stored factors, use steps 6-8.)					
6. Enter $F_p()$ or glassing factor	$F_p()$ F_G	A'	$\left\{ \begin{matrix} F_p() \\ F_G \end{matrix} \right\}$	Fv (Rad) Fv (II) P_{mp} EOL V_{mp} EOL	tc = temperature cycling factor Rad = radiation degradation factor Π = product of all individual factors P_{mp} EOL = EOL solar cell maximum power V_{mp} EOL = EOL solar cell maximum voltage
7. Enter $F_v()$ or cover degradation factor	$F_v()$ F_T	B'	$\left\{ \begin{matrix} F_v() \\ F_T \end{matrix} \right\}$		F_G = glassing factor $F_v()$ = solar cell voltage performance factor
8. Enter ID # and store factors	#	C'	-		

(NOTE: ID #'s for the various factors are as follows:)

ID #	FACTOR
0	F_G/F_T
1	T_{op}
2	A
3	V_D

PROCEDURE ENTER PRESS DISPLAY PRINT REMARKS

4 V_{SC}
 5 V_{MM}
 6 V_{PP}
 7 V_{th}
 8 V_{sr}
 9 Leak
 10 t_c
 -21 Rad

1.2.8 Use of Solar Array Subroutine (479.59)

1. Store EOL solar cell
maximum power
2. Store EOL solar cell
maximum voltage
3. Compute/print solar
array configuration

$P_{mp}(EOL)$ A $P_{mp}(EOL)$

$V_{mp}(EOL)$ B $V_{mp}(EOL)$

C

Cell power

Cell voltage

cells in series

cells in parallel

cells/ i -module

i -module power

i -module voltage

cells in L direction/module

cells in W direction/module

cells/module

W

V

S

//

C

W

V

X

Y

C

PROCEDURE

ENTER

PRESS

DISPLAY

PRINT

REMARKS

M	Module width
M	Module length
M ²	Module area
KG	Weight of module solar cells
KG	Weight of module substrate
KG	Total module weight
W	Panel power
V	Panel voltage
M	Panel length
M	Panel width
W	Channel power
V	Channel voltage
W	Blanket power
V	Blanket voltage
M	Folded blanket length
M	Blanket width
M	Unfolded blanket length
W	Wing power
V	Wing Voltage
W	Total array power
V	Array bus voltage
M ²	Total array area

1.2.9 Use of Weight Subroutine (479.59)

1. Compute/print array weights,

W/m² and W/KG

C

"WEIGHT"

Weights as follows:

PROCEDUREENTERPRESSDISPLAYPRINTREMARKS

MOD	Module total/panel
EIC1	Electrical interconnects
PAN	Total/panel
PAN	Panel total/blanket
MEIC	Panel/panel mechanical interconnect
END	Blanket end pieces (2)
EIC	Panel/panel electrical interconnects
BLKT	Total blanket
BLKT	Blanket total/array
MB	Main bus conductors
STR	Structure total
TOT	Total array weight
W/m^2	Total array W/m^2
W/KG	Total array W/KG
R_{12}	Stored data base -- various
+	array parameters
R_{59}	
R_{12}	
+	
R_{59}	

2 Print data base

D

1.2.2.10 Use of LCCM Subroutine (479.59)

(NOTE: If solar cell, cover or cell/cover assembly component costs \neq baseline numbers, use step 1a, 1b, or 1c as appropriate.)

<u>PROCEDURE</u>	<u>ENTER</u>	<u>PRESS</u>	<u>DISPLAY</u>	<u>PRINT</u>	<u>REMARKS</u>
1a. Enter solar cell unit cost	$\$_{sc}$	B	$\$_{sc}$		$\$_{sc}$ = Solar cell unit cost
1b. Enter cover unit cost	$\$_c$	B'	$\$_c$		$\$_c$ = Cover unit cost
1c. Enter cell/cover assembly unit cost	$\$_{CCA}$	SBR INV	$\$_{CCA}$		$\$_{CCA}$ = Cell/cover assembly unit cost
2. Compute/print life cycle cost		C		R_{53} R_{54} R_{55} R_{56} R_{57} R_{58} R_{59}	Total # solar cells Total area of module substrate Total # modules Total # panels Weight of structures & main bus Combined weight of blankets Weight/panel
				R_4 $+$ R_{29}	LCCM cost factors
				L_1 L_2 L_3 L_4 L_5 L_6	Labor \$ in millions L_1 = Blanket assembly L_2 = Cell/cover assembly L_3 = Module substrate L_4 = Module assembly L_5 = Panel assembly L_6 = Structure packaging

PROCEDUREENTERPRESSDISPLAYPRINTREMARKS L_7 = Blanket packaging L_T = Total Labor \$Material \$ in Millions M_1 = Blanket assembly M_2 = Cell/cover assembly M_3 = Module substrate M_4 = Module assembly M_5 = Panel assembly M_6 = Structure M_T = Total Material \$LCC \$ in Millions

Manufacturing direct labor

Total Labor (w/burden)

Manufacturing materials

Materials burden

Manufacturing equipment

Equipment maintenance

Manufacturing special equipment

Surface transportation

Total manufacturing non-labor

Manufacturing subtotal

Total manufacturing (contractor)

Space transportation

Space assembly/checkout

Total NASA (production)

Total production phase

"LCCM"

35

36

37

38

39

40

41

42

43

44

45

46

47

48

49

PROCEDURE

ENTER

PRESS

DISPLAY

PRINT

REMARKS

50	Total DDT&E phase
51	Direct labor (O&M)
52	Labor subtotal (O&M)
53	Total contractor (O&M)
54	Crew training (O&M)
55	Crew Transport (O&M)
56	Perform Maintenance (O&M)
57	Total NASA (O&M)
58	Total O&M phase
59	Total LCC

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Coding Form

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LBL		055	87	IFF		110	04	4	
001	50	IXI		056	04	04		111	03	3	
002	44	SUM		057	49	PRD		112	69	DP	
003	18	18		058	94	+/-		113	04	04	
004	32	XIT		059	76	LBL		114	43	RCL	
005	44	SUM		060	49	PRD		115	03	03	
006	17	17		061	98	ADV		116	69	DP	
007	61	GTO		062	69	DP		117	06	06	
008	55	+		063	06	06		118	85	+	
009	76	LBL		064	92	RTN		119	07	7	
010	57	ENG		065	76	LBL		120	05	5	
011	44	SUM		066	16	A'		121	04	4	
012	16	16		067	42	STO		122	03	3	
013	32	XIT		068	01	01		123	69	DP	
014	44	SUM		069	92	RTN		124	04	04	
015	15	15		070	76	LBL		125	43	RCL	
016	61	GTO		071	17	B'		126	04	04	
017	53	(		072	42	STO		127	69	DP	
018	76	LBL		073	02	02		128	06	06	
019	58	FIX		074	92	RTN		129	95	=	
020	44	SUM		075	76	LBL		130	58	FIX	
021	14	14		076	18	C'		131	03	03	
022	32	XIT		077	42	STO		132	52	EE	
023	44	SUM		078	03	03		133	22	INV	
024	13	13		079	92	RTN		134	52	EE	
025	61	GTO		080	76	LBL		135	42	STO	
026	53	(		081	19	D'		136	06	06	
027	76	LBL		082	42	STO		137	43	RCL	
028	43	RCL		083	04	04		138	01	01	
029	73	RC*		084	92	RTN		139	65	X	
030	00	00		085	76	LBL		140	43	RCL	
031	87	IFF		086	11	A		141	03	03	
032	00	00		087	02	2		142	95	=	
033	30	TAN		088	07	7		143	52	EE	
034	53	(		089	69	DP		144	22	INV	
035	43	RCL		090	04	04		145	52	EE	
036	12	12		091	43	RCL		146	22	INV	
037	85	+		092	01	01		147	58	FIX	
038	43	RCL		093	98	ADV		148	42	STO	
039	14	14		094	69	DP		149	05	05	
040	85	+		095	06	06		150	01	1	
041	43	RCL		096	85	+		151	03	3	
042	16	16		097	07	7		152	01	1	
043	54	)		098	05	5		153	05	5	
044	76	LBL		099	02	2		154	69	DP	
045	30	TAN		100	07	7		155	04	04	
046	92	RTN		101	69	DP		156	43	RCL	
047	76	LBL		102	04	04		157	05	05	
048	23	LNK		103	43	RCL		158	69	DP	
049	03	3		104	02	02		159	06	06	
050	07	7		105	69	DP					
051	69	DP		106	06	06					
052	04	04		107	95	=					
053	43	RCL		108	65	X					
054	09	09		109	53	(

MERGED CODES

82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89
62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59

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LOC CODE	KEY	COMMENTS	LOC CODE	KEY	COMMENTS	LOC CODE	KEY	COMMENTS
160	55	-	215	68	NOP	270	52	EE
161	01	1	216	32	INV	271	22	INV
162	03	3	217	76	LBL	272	52	EE
163	03	3	218	68	NOP	273	22	INV
164	06	6	219	86	STF	274	58	FIX
165	69	OP	220	00	00	275	42	STD
166	04	04	221	32	X:T	276	08	08
167	43	RCL	222	01	1	277	03	3
168	06	06	223	67	EQ	278	00	0
169	69	OP	224	69	OP	279	69	OP
170	06	06	225	22	INV	280	04	04
171	95	=	226	76	LBL	281	43	RCL
172	58	FIX	227	69	OP	282	08	08
173	03	03	228	86	STF	283	69	OP
174	52	EE	229	01	01	284	06	06
175	22	INV	230	02	2	285	65	X
176	52	EE	231	67	EQ	286	01	1
177	22	INV	232	79	X	287	03	3
178	58	FIX	233	22	INV	288	69	OP
179	42	STD	234	76	LBL	289	04	04
180	07	07	235	79	X	290	43	RCL
181	03	3	236	86	STF	291	06	06
182	03	3	237	02	02	292	87	IFF
183	02	2	238	03	3	293	03	03
184	01	1	239	67	EQ	294	22	INV
185	69	OP	240	89	#	295	43	RCL
186	04	04	241	22	INV	296	05	05
187	43	RCL	242	76	LBL	297	76	LBL
188	07	07	243	89	#	298	22	INV
189	69	OP	244	86	STF	299	69	OP
190	06	06	245	03	03	300	06	06
191	92	RTN	246	71	SBR	301	55	+
192	76	LBL	247	23	LNK	302	01	1
193	13	C	248	65	X	303	00	0
194	42	STD	249	32	X:T	304	95	=
195	09	09	250	01	1	305	58	FIX
196	92	RTN	251	06	6	306	04	04
197	76	LBL	252	69	OP	307	52	EE
198	14	D	253	04	04	308	22	INV
199	42	STD	254	43	RCL	309	52	EE
200	10	10	255	10	10	310	22	INV
201	92	RTN	256	69	OP	311	58	FIX
202	76	LBL	257	06	06	312	42	STD
203	10	E'	258	65	X	313	08	08
204	22	INV	259	02	2	314	87	IFF
205	76	LBL	260	05	5	315	02	02
206	15	E	261	04	4	316	58	FIX
207	86	STF	262	52	EE	317	87	IFF
208	04	04	263	07	7	318	03	03
209	98	ADV	264	94	+/-	319	57	ENG
210	98	ADV	265	22	INV			
211	99	PRT	266	52	EE			
212	59	INT	267	95	=			
213	69	OP	268	58	FIX			
214	67	EQ	269	04	04			

MERGED CODES

82	83	84	72	73	74	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
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LOC CODE	KEY	COMMENTS	LOC CODE	KEY	COMMENTS	LOC CODE	KEY	COMMENTS
320	44	SUM	375	52	EE	430	76	LBL
321	12	12	376	22	INV	431	34	FX
322	32	XIT	377	52	EE	432	69	OP
323	44	SUM	378	22	INV	433	04	04
324	11	11	379	58	FIX	434	43	RCL
325	76	LBL	380	87	IFF	435	08	08
326	53	(	381	00	00	436	98	RDV
327	04	4	382	50	IXI	437	69	OP
328	03	3	383	44	SUM	438	06	06
329	69	OP	384	20	20	439	92	RTN
330	04	04	385	32	XIT	440	76	LBL
331	43	RCL	386	44	SUM	441	35	1/X
332	08	08	387	19	19	442	32	XIT
333	69	OP	388	76	LBL	443	01	1
334	06	06	389	55	+	444	05	5
335	71	SBR	390	03	3	445	03	3
336	23	LNK	391	07	7	446	03	3
337	65	X	392	06	6	447	69	OP
338	32	XIT	393	05	5	448	04	04
339	01	1	394	69	OP	449	32	XIT
340	06	6	395	04	04	450	69	OP
341	69	OP	396	32	XIT	451	06	06
342	04	04	397	69	OP	452	65	X
343	53	(	398	06	06	453	03	3
344	43	RCL	399	43	RCL	454	00	0
345	10	10	400	08	08	455	01	1
346	22	INV	401	55	+	456	05	5
347	87	IFF	402	43	RCL	457	03	3
348	01	01	403	06	06	458	03	3
349	33	X ²	404	65	X	459	69	OP
350	65	X	405	01	1	460	04	04
351	93	.	406	00	0	461	43	RCL
352	03	3	407	95	=	462	08	08
353	07	7	408	58	FIX	463	95	=
354	05	5	409	04	04	464	58	FIX
355	54	)	410	52	EE	465	00	00
356	58	FIX	411	22	INV	466	52	EE
357	00	00	412	52	EE	467	22	INV
358	52	EE	413	22	INV	468	52	EE
359	22	INV	414	58	FIX	469	22	INV
360	52	EE	415	42	STD	470	58	FIX
361	22	INV	416	08	08	471	69	OP
362	58	FIX	417	02	2	472	06	06
363	76	LBL	418	00	0	473	69	OP
364	33	X ²	419	42	STD	474	20	20
365	69	OP	420	00	00	475	74	SM#
366	06	06	421	03	3	476	00	00
367	55	+	422	00	0	477	92	RTN
368	02	2	423	87	IFF	478	61	GTO
369	02	2	424	03	03	479	35	1/X
370	00	0	425	34	FX			
371	00	0	426	03	3			
372	95	=	427	00	0			
373	58	FIX	428	06	6			
374	02	02	429	05	5			

MERGE CODES

62	72	82
63	73	83
64	74	84

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LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
480	76	LBL		535	52	EE		590	69	OP	
481	45	YX		536	07	7		591	06	06	
482	42	STD		537	94	+/-		592	65	X	
483	09	09		538	23	INV		593	02	2	
484	35	1/X		539	52	EE		594	03	3	
485	65	X		540	95	=		595	00	0	
486	71	SBR		541	58	FIX		596	00	0	
487	43	RCL		542	00	00		597	95	=	
488	65	X		543	52	EE		598	32	XIT	
489	01	1		544	22	INV		599	01	1	
490	00	0		545	52	EE		600	06	6	
491	95	=		546	22	INV		601	69	OP	
492	58	FIX		547	58	FIX		602	04	04	
493	04	04		548	69	OP		603	32	XIT	
494	52	EE		549	06	06		604	58	FIX	
495	23	INV		550	03	3		605	00	00	
496	52	EE		551	00	0		606	69	OP	
497	22	INV		552	69	OP		607	06	06	
498	58	FIX		553	04	04		608	22	INV	
499	42	STD		554	43	RCL		609	58	FIX	
500	10	10		555	10	10		610	03	3	
501	55	+		556	69	OP		611	07	7	
502	03	3		557	06	06		612	06	6	
503	07	7		558	01	1		613	05	5	
504	69	OP		559	03	3		614	69	OP	
505	04	04		560	69	OP		615	04	04	
506	69	OP		561	04	04		616	69	OP	
507	30	30		562	43	RCL		617	20	20	
508	73	RC*		563	09	09		618	73	RC*	
509	00	00		564	69	OP		619	00	00	
510	87	IFF		565	06	06		620	69	OP	
511	00	00		566	04	4		621	06	06	
512	48	EXC		567	03	3		622	92	RTN	
513	53	(		568	69	OP		623	76	LBL	
514	43	RCL		569	04	04		624	12	8	
515	11	11		570	69	OP		625	86	STF	
516	85	+		571	20	20		626	00	00	
517	43	RCL		572	71	SBR		627	07	7	
518	13	13		573	43	RCL		628	07	7	
519	85	+		574	69	OP		629	04	4	
520	43	RCL		575	06	06		630	07	7	
521	15	15		576	92	RTN		631	52	EE	
522	54	)		577	76	LBL		632	06	6	
523	76	LBL		578	70	RAD		633	22	INV	
524	48	EXC		579	73	RC*		634	52	EE	
525	69	OP		580	00	00		635	98	ADV	
526	06	06		581	55	+		636	98	ADV	
527	55	+		582	03	3		637	69	OP	
528	01	1		583	07	7		638	00	00	
529	06	6		584	69	OP		639	69	OP	
530	69	OP		585	04	04					
531	04	04		586	69	OP					
532	02	2		587	30	30					
533	05	5		588	73	RC*					
534	04	4		589	00	00					

MERGED CODES			
62	72	82	92
63	73	83	93
64	74	84	94

TEXAS INSTRUMENTS
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TITLE PHYSICALPAGE 5 OF 5TI Programmable
Coding Form

PROGRAMMER _____

DATE _____

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
640	03	03		695	08	8					
641	89	OP		696	42	STD					
642	05	05		697	00	00					
643	11	A		698	07	7					
644	01	1		699	98	ADV					
645	98	ADV		700	99	PRT					
646	99	PRT		701	71	SBR					
647	01	1		702	70	RAD					
648	02	2		703	02	2					
649	42	STD		704	44	SUM					
650	00	00		705	00	00					
651	43	RCL		706	08	8					
652	05	05		707	98	ADV					
653	71	SBR		708	99	PRT					
654	45	YX		709	71	SBR					
655	29	CP		710	70	RAD					
656	43	RCL		711	98	ADV					
657	13	13		712	02	2					
658	67	EO		713	01	1					
659	60	DEG		714	22	INV					
660	02	2		715	90	LST					
661	98	ADV		716	92	RTN					
662	99	PRT		717	00	0					
663	01	1		718	00	0					
664	04	4		719	00	0					
665	42	STD									
666	00	00									
667	43	RCL									
668	05	05									
669	71	SBR									
670	45	YX									
671	76	LBL									
672	60	DEG									
673	03	3									
674	98	ADV									
675	99	PRT									
676	01	1									
677	06	6									
678	42	STD									
679	00	00									
680	43	RCL									
681	06	06									
682	71	SBR									
683	45	YX									
684	22	INV									
685	86	STF									
686	00	00									
687	05	5									
688	98	ADV									
689	99	PRT									
690	43	RCL									
691	06	06									
692	71	SBR									
693	45	YX									
694	01	1									

MERGED CODES

62	63	64	72	73	74	83	84	92
STD	RCL	YX	STD	RCL	SUM	STD	RCL	ADV

TEXAS INSTRUMENTS
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PROGRAMMER _____ DATE _____

TI Programmable
Coding Form 

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LBL		055	09	09		110	73	RC*	
001	99	PRT		056	92	RTN		111	09	09	
002	02	2		057	76	LBL		112	85	+	
003	06	6		058	73	NOP		113	69	DP	
004	03	3		059	23	LNK		114	29	29	
005	00	0		060	32	X:T		115	73	RC*	
006	69	DP		061	43	RCL		116	09	09	
007	04	04		062	32	32		117	65	X	
008	43	RCL		063	22	INV		118	43	RCL	
009	13	13		064	59	INT		119	13	13	
010	98	ADV		065	65	X		120	23	LNK	
011	98	ADV		066	01	1		121	95	=	
012	69	DP		067	00	0		122	23	LNK	
013	06	06		068	00	0		123	76	Z+	
014	04	4		069	00	0		124	92	RTN	
015	05	5		070	00	0		125	76	LBL	
016	03	3		071	95	=		126	33	X ²	
017	05	5		072	42	STD		127	43	RCL	
018	03	3		073	32	32		128	46	46	
019	06	6		074	59	INT		129	42	STD	
020	69	DP		075	55	+		130	00	00	
021	04	04		076	01	1		131	76	LBL	
022	43	RCL		077	00	0		132	24	CE	
023	45	45		078	95	=		133	03	3	
024	69	DP		079	76	Z+		134	03	3	
025	06	06		080	92	RTN		135	42	STD	
026	92	RTN		081	76	LBL		136	09	09	
027	76	LBL		082	67	EQ		137	69	DP	
028	69	DP		083	36	PGM		138	20	20	
029	73	RC*		084	01	01		139	71	SBR	
030	00	00		085	71	SBR		140	69	DP	
031	42	STD		086	25	CLR		141	22	INV	
032	32	32		087	03	3		142	77	GE	
033	59	INT		088	07	7		143	24	CE	
034	55	+		089	00	0		144	71	SBR	
035	01	1		090	71	SBR		145	67	EQ	
036	00	0		091	68	NOP		146	69	DP	
037	95	=		092	05	5		147	30	30	
038	69	DP		093	05	5		148	61	GTO	
039	29	29		094	06	6		149	35	1/X	
040	72	ST*		095	71	SBR		150	76	LBL	
041	09	09		096	68	NOP		151	57	ENG	
042	92	RTN		097	71	SBR		152	04	4	
043	76	LBL		098	60	DEG		153	08	8	
044	60	DEG		099	92	RTN		154	42	STD	
045	69	DP		100	76	LBL		155	46	46	
046	12	12		101	78	Z+		156	05	5	
047	69	DP		102	69	DP		157	01	1	
048	29	29		103	29	29		158	61	GTO	
049	72	ST*		104	73	RC*		159	50	IXI	
050	09	09		105	09	09					
051	32	X:T		106	23	LNK					
052	69	DP		107	32	X:T					
053	29	29		108	69	DP					
054	72	ST*		109	29	29					

MERGED CODES			
62	72	63	73
63	73	64	74
64	74	65	75

TEXAS INSTRUMENTS
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TITLE FLUENCE ϕ PAGE 2 OF 3TI Programmable
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DATE _____

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
160	76	LBL		215	58	FIX		270	69	DP	
161	58	FIX		216	01	1		271	71	SBR	
162	05	5		217	00	0		272	67	EQ	
163	02	2		218	67	EQ		273	03	3	
164	42	STD		219	59	INT		274	03	3	
165	46	46		220	29	CP		275	42	STD	
166	05	5		221	76	LBL		276	09	09	
167	05	5		222	50	IxI		277	36	PGM	
168	61	GTO		223	42	STD		278	01	01	
169	50	IxI		224	47	47		279	71	SBR	
170	76	LBL		225	32	XIT		280	25	CLR	
171	59	INT		226	42	STD		281	71	SBR	
172	05	5		227	45	45		282	78	Z+	
173	06	6		228	92	RTN		283	71	SBR	
174	42	STD		229	76	LBL		284	78	Z+	
175	46	46		230	14	D		285	69	DP	
176	05	5		231	32	XIT		286	12	12	
177	09	9		232	71	SBR		287	22	INV	
178	61	GTO		233	99	PRT		288	23	LNx	
179	50	IxI		234	32	XIT		289	65	X	
180	76	LBL		235	76	LBL		290	22	INV	
181	16	R'		236	19	D'		291	58	FIX	
182	36	PGM		237	42	STD		292	03	3	
183	24	24		238	33	33		293	07	7	
184	10	E'		239	76	LBL		294	06	6	
185	36	PGM		240	89	1		295	05	5	
186	24	24		241	43	RCL		296	69	DP	
187	14	D		242	33	33		297	04	04	
188	58	FIX		243	32	XIT		298	43	RCL	
189	00	00		244	06	6		299	33	33	
190	52	EE		245	77	GE		300	98	ADV	
191	22	INV		246	33	X2		301	69	DP	
192	52	EE		247	43	RCL		302	06	06	
193	76	LBL		248	47	47		303	45	YX	
194	11	R		249	42	STD		304	32	XIT	
195	42	STD		250	00	00		305	95	=	
196	13	13		251	76	LBL		306	32	XIT	
197	22	INV		252	28	LOG		307	02	2	
198	58	FIX		253	03	3		308	01	1	
199	06	6		254	03	3		309	69	DP	
200	69	DP		255	42	STD		310	04	04	
201	17	17		256	09	09		311	32	XIT	
202	43	RCL		257	69	DP		312	58	FIX	
203	13	13		258	30	30		313	02	02	
204	92	RTN		259	71	SBR		314	52	EE	
205	76	LBL		260	69	DP		315	22	INV	
206	12	8		261	77	GE		316	52	EE	
207	32	XIT		262	28	LOG		317	69	DP	
208	02	2		263	71	SBR		318	06	06	
209	93	.		264	67	EQ		319	22	INV	
210	05	5		265	69	DP					
211	67	EQ		266	20	20					
212	57	ENG		267	76	LBL					
213	05	5		268	35	1/X					
214	67	EQ		269	71	SBR					

MERGED CODES

82	72	83
83	73	84
84	74	85

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PROGRAMMER _____ DATE _____

TI Programmable
Coding Form 

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
320	58	FIX		375	85	+					
321	92	RTN		376	43	RCL					
322	76	LBL		377	14	14					
323	15	E		378	95	=					
324	25	CLR		379	55	+					
325	42	STD		380	01	1					
326	33	33		381	00	0					
327	01	1		382	00	0					
328	08	8		383	00	0					
329	42	STD		384	85	+					
330	07	07		385	43	RCL					
331	71	SBR		386	16	16					
332	99	PRT		387	65	X					
333	76	LBL		388	01	1					
334	45	YX		389	52	EE					
335	01	1		390	04	4					
336	44	SUM		391	22	INV					
337	33	33		392	52	EE					
338	71	SBR		393	95	=					
339	89	#		394	42	STD					
340	97	DSZ		395	11	11					
341	07	07		396	43	RCL					
342	45	YX		397	13	13					
343	92	RTN		398	42	STD					
344	76	LBL		399	12	12					
345	13	C		400	43	RCL					
346	25	CLR		401	18	18					
347	43	RCL		402	14	D					
348	01	01		403	42	STD					
349	85	+		404	10	10					
350	43	RCL		405	43	RCL					
351	02	02		406	20	20					
352	95	=		407	19	D'					
353	65	X		408	44	SUM					
354	01	1		409	10	10					
355	00	0		410	07	7					
356	00	0		411	07	7					
357	00	0		412	02	2					
358	85	+		413	01	1					
359	53	<		414	69	DP					
360	43	RCL		415	04	04					
361	03	03		416	43	RCL					
362	85	+		417	10	10					
363	43	RCL		418	98	ADV					
364	04	04		419	69	DP					
365	54	>		420	06	06					
366	55	+		421	92	RTN					
367	01	1		422	00	0					
368	00	0		423	00	0					
369	00	0		424	00	0					
370	95	=									
371	42	STD									
372	08	08									
373	43	RCL									
374	12	12									

MERGED CODES											
62	OP	01	72	STD	01	83	STD	01			
63	OP	02	73	RCL	01	84	OP	01			
64	OP	03	74	SUM	01	92	INV	01			

TEXAS INSTRUMENTS
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DATA BASE
FOR
FLUENCE, ϕ
PROGRAM

0.	30
0.	31
0.	32
0.	33
0.	34
0.	35
0.	36
0.	37
0.	38
0.	39
0.	40
0.	41
0.	42
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0.	44
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56.	46
59.	47
30.0250032	48
60.0130016	49
120.00550071	50
157.00390051	51
30.0280041	52
60.0140021	53
120.00610093	54
157.004300867	55
30.0330059	56
60.01700296	57
120.007301437	58
157.005201	59

TITLE RADIATIONPAGE 1 OF 3TI Programmable
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PROGRAMMER _____

DATE _____

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LBL		055	12	12		110	43	43	
001	12	B		056	85	+		111	95	=	
002	42	STO		057	32	XIT		112	42	STO	
003	39	39		058	65	X		113	33	33	
004	92	RTN		059	43	RCL		114	32	INV	
005	76	LBL		060	32	32		115	59	INT	
006	16	R		061	23	LNX		116	87	IFF	
007	22	INV		062	76	LBL		117	01	01	
008	58	FIN		063	34	FX		118	37	P/R	
009	69	OP		064	95	=		119	43	RCL	
010	04	04		065	58	FIN		120	33	33	
011	32	XIT		066	03	03		121	59	INT	
012	69	OP		067	52	EE		122	55	+	
013	06	06		068	22	INV		123	43	RCL	
014	92	RTN		069	52	EE		124	43	43	
015	76	LBL		070	92	RTN		125	95	=	
016	55	-		071	76	LBL		126	76	LBL	
017	73	RC*		072	33	X ²		127	37	P/R	
018	30	30		073	36	PGM		128	78	Z+	
019	59	INT		074	01	01		129	69	OP	
020	23	LNX		075	71	SBR		130	12	12	
021	32	XIT		076	25	CLR		131	85	+	
022	73	RC*		077	43	RCL		132	32	XIT	
023	30	30		078	41	41		133	65	X	
024	22	INV		079	32	XIT		134	43	RCL	
025	59	INT		080	43	RCL		135	39	39	
026	78	Z+		081	39	39		136	71	SBR	
027	92	RTN		082	22	INV		137	34	FX	
028	76	LBL		083	77	GE		138	92	RTN	
029	45	YX		084	28	LDG		139	76	LBL	
030	01	1		085	22	INV		140	15	E	
031	22	INV		086	76	LBL		141	01	1	
032	87	IFF		087	28	LDG		142	19	D ⁺	
033	00	00		088	86	STF		143	01	1	
034	98	ADV		089	01	01		144	00	0	
035	94	+/-		090	73	RC*		145	14	D	
036	61	GTO		091	31	31		146	02	2	
037	98	ADV		092	22	INV		147	00	0	
038	76	LBL		093	59	INT		148	14	D	
039	44	SUM		094	78	Z+		149	04	4	
040	01	1		095	43	RCL		150	00	0	
041	87	IFF		096	40	40		151	14	D	
042	00	00		097	87	IFF		152	01	1	
043	98	ADV		098	01	01		153	00	0	
044	94	+/-		099	29	CP		154	00	0	
045	76	LBL		100	43	RCL		155	14	D	
046	98	ADV		101	42	42		156	02	2	
047	44	SUM		102	76	LBL		157	00	0	
048	30	30		103	29	CP		158	00	0	
049	44	SUM		104	32	XIT		159	14	D	
050	31	31		105	73	RC*					
051	92	RTN		106	31	31					
052	76	LBL		107	59	INT					
053	61	GTO		108	55	+					
054	69	OP		109	43	RCL					

MERGED CODES

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63 <input type="checkbox"/>	73 <input checked="" type="checkbox"/>	84 <input type="checkbox"/>
64 <input type="checkbox"/>	74 <input checked="" type="checkbox"/>	92 <input type="checkbox"/>

TEXAS INSTRUMENTS
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TITLE RADIATION

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TI Programmable



PROGRAMMER

DATE

Coding Form

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
160	04	4		215	05	5		270	77	GE	
161	00	0		216	03	3		271	53	C	
162	00	0		217	07	7		272	36	PGM	
163	14	D		218	16	R		273	01	01	
164	43	RCL		219	76	LBL		274	71	SBR	
165	43	43		220	39	COS		275	35	CLR	
166	14	D		221	98	RDV		276	71	SBR	
167	98	RTN		222	43	RCL		277	55	+	
168	76	LBL		223	32	32		278	71	SBR	
169	13	C		224	32	XIT		279	45	YX	
170	43	RCL		225	07	7		280	71	SBR	
171	10	10		226	07	7		281	55	+	
172	19	D		227	02	2		282	71	SBR	
173	98	RTN		228	01	1		283	61	GTO	
174	76	LBL		229	16	R		284	42	STO	
175	19	D		230	32	XIT		285	10	10	
176	23	INV		231	04	4		286	71	SBR	
177	76	LBL		232	00	0		287	33	Y2	
178	14	D		233	77	GE		288	42	STO	
179	98	STF		234	57	ENG		289	34	34	
180	02	02		235	23	INV		290	71	SBR	
181	43	STO		236	76	LBL		291	44	SUM	
182	32	32		237	57	ENG		292	71	SBR	
183	23	INV		238	96	STF		293	33	X2	
184	58	FIX		239	00	00		294	42	STO	
185	98	IFF		240	05	5		295	35	35	
186	02	02		241	02	2		296	36	PGM	
187	39	COS		242	87	IFF		297	01	01	
188	03	3		243	00	00		298	71	SBR	
189	05	5		244	97	DSZ		299	25	CLR	
190	69	OP		245	05	5		300	73	RC*	
191	00	00		246	09	9		301	30	30	
192	69	OP		247	76	LBL		302	59	INT	
193	02	02		248	97	DSZ		303	23	LNX	
194	01	1		249	42	STO		304	32	XIT	
195	03	3		250	30	30		305	43	RCL	
196	01	1		251	75	-		306	35	35	
197	06	6		252	08	8		307	78	Z+	
198	00	0		253	95	=		308	71	SBR	
199	00	0		254	42	STO		309	45	YX	
200	00	0		255	31	31		310	73	RC*	
201	00	0		256	76	LBL		311	30	30	
202	00	0		257	53	C		312	59	INT	
203	00	0		258	71	SBR		313	23	LNX	
204	69	OP		259	44	SUM		314	32	XIT	
205	03	03		260	73	RC*		315	43	RCL	
206	98	RDV		261	30	30		316	34	34	
207	98	RDV		262	59	INT		317	78	Z+	
208	69	OP		263	22	INV		318	71	SBR	
209	05	05		264	87	IFF		319	61	GTO	
210	98	RDV		265	00	00					
211	43	RCL		266	38	SIN					
212	39	39		267	22	INV					
213	32	XIT		268	76	LBL					
214	01	1		269	38	SIN					

MERGED CODES

62	72	82	92
63	73	83	93
64	74	84	94

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TI-841B1

PROGRAMMER

DATE

[illegible]

DATA BASE
FOR
RATIIATION
PROGRAM

0.	30
0.	31
0.	32
0.	33
0.	34
0.	35
0.	36
0.	37
0.	38
8.	39
3.4	40
5.7	41
11.8	42
1000.	43
995995.995	44
883977.966	45
841960.934	46
795928.893	47
723878.811	48
661824.749	49
604746.685	50
517647.586	51
1.995	52
10.991	53
20.982	54
40.969	55
100.946	56
200.923	57
400.898	58
1000.863	59

TITLE THERMALPAGE 1 OF 3TI Programmable
Coding Form

PROGRAMMER _____

DATE _____

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LBL		055	43	RCL		110	92	RTN	
001	34	FX		056	06	06		111	76	LBL	
002	58	FIX		057	99	PRT		112	24	CE	
003	01	01		058	65	X		113	42	STO	
004	69	DP		059	43	RCL		114	03	03	
005	22	22		060	05	05		115	92	RTN	
006	73	RC*		061	99	PRT		116	76	LBL	
007	02	02		062	95	=		117	11	A	
008	52	EE		063	58	FIX		118	69	DP	
009	22	INV		064	03	03		119	00	00	
010	52	EE		065	52	EE		120	03	3	
011	22	INV		066	22	INV		121	07	7	
012	58	FIX		067	52	EE		122	02	2	
013	72	ST*		068	22	INV		123	03	3	
014	02	02		069	58	FIX		124	01	1	
015	92	RTN		070	92	RTN		125	07	7	
016	76	LBL		071	76	LBL		126	69	DP	
017	88	DMS		072	22	INV		127	02	02	
018	98	ADV		073	36	PGM		128	03	3	
019	99	PRT		074	24	24		129	05	5	
020	43	RCL		075	10	E'		130	03	3	
021	06	06		076	36	PGM		131	00	0	
022	99	PRT		077	24	24		132	01	1	
023	65	X		078	14	D		133	03	3	
024	43	RCL		079	58	FIX		134	02	2	
025	07	07		080	00	00		135	07	7	
026	99	PRT		081	52	EE		136	00	0	
027	85	+		082	22	INV		137	00	0	
028	43	RCL		083	52	EE		138	69	DP	
029	05	05		084	22	INV		139	03	03	
030	99	PRT		085	58	FIX		140	98	ADV	
031	65	X		086	76	LBL		141	98	ADV	
032	53	(		087	32	XIT		142	69	DP	
033	01	1		088	42	STO		143	05	05	
034	75	-		089	12	12		144	00	0	
035	43	RCL		090	92	RTN		145	98	ADV	
036	07	07		091	76	LBL		146	99	PRT	
037	54	)		092	23	LNK		147	09	9	
038	99	PRT		093	42	STO		148	00	0	
039	95	=		094	07	07		149	75	-	
040	58	FIX		095	92	RTN		150	53	(
041	03	03		096	76	LBL		151	06	6	
042	52	EE		097	12	B		152	03	3	
043	22	INV		098	42	STO		153	07	7	
044	52	EE		099	06	06		154	02	2	
045	99	PRT		100	92	RTN		155	55	+	
046	22	INV		101	76	LBL		156	53	(
047	58	FIX		102	13	C		157	24	CE	
048	92	RTN		103	42	STO		158	85	+	
049	76	LBL		104	05	05		159	43	RCL	
050	86	STF		105	92	RTN					
051	43	RCL		106	76	LBL					
052	07	07		107	14	D					
053	99	PRT		108	42	STO					
054	65	X		109	04	04					

MERGED CODES

62	72	83
63	73	84
64	74	92

TEXAS INSTRUMENTS
INCORPORATED

TI-24181

TITLE THERMAL PAGE 2 OF 3

PROGRAMMER _____ DATE _____

TI Programmable
Coding Form 

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
160	12	12		215	95	=		270	99	PRT	
161	99	PRT		216	52	EE		271	42	STO	
162	54	)		217	22	INV		272	16	16	
163	42	STO		218	52	EE		273	65	X	
164	14	14		219	99	PRT		274	02	2	
165	54	)		220	22	INV		275	00	0	
166	22	INV		221	58	FIX		276	08	8	
167	38	SIN		222	92	RTN		277	93	.	
168	42	STO		223	76	LBL		278	02	2	
169	04	04		224	16	R'		279	49	PRD	
170	95	=		225	01	1		280	17	17	
171	99	PRT		226	71	SBR		281	95	=	
172	42	STO		227	88	DMS		282	42	STO	
173	13	13		228	42	STO		283	18	18	
174	43	RCL		229	15	15		284	43	RCL	
175	14	14		230	42	STO		285	15	15	
176	52	EE		231	17	17		286	99	PRT	
177	03	3		232	92	RTN		287	22	INV	
178	45	YX		233	76	LBL		288	58	FIX	
179	03	3		234	17	B'		289	92	RTN	
180	65	X		235	02	2		290	76	LBL	
181	08	8		236	98	ADV		291	19	D'	
182	93	.		237	99	PRT		292	25	CLR	
183	06	6		238	43	RCL		293	42	STO	
184	05	5		239	07	07		294	19	19	
185	03	3		240	42	STO		295	93	.	
186	52	EE		241	09	09		296	07	7	
187	01	1		242	71	SBR		297	05	5	
188	04	4		243	86	STF		298	42	STO	
189	94	+/-		244	99	PRT		299	03	03	
190	22	INV		245	65	X		300	04	4	
191	52	EE		246	32	X:T		301	71	SBR	
192	95	=		247	01	1		302	88	DMS	
193	34	FX		248	00	0		303	42	STO	
194	55	+		249	00	0		304	20	20	
195	06	6		250	00	0		305	92	RTN	
196	00	0		251	95	=		306	76	LBL	
197	95	=		252	44	SUM		307	15	E	
198	58	FIX		253	09	09		308	22	INV	
199	02	02		254	32	X:T		309	76	LBL	
200	52	EE		255	22	INV		310	10	E'	
201	22	INV		256	58	FIX		311	86	STF	
202	52	EE		257	22	INV		312	00	00	
203	99	PRT		258	44	SUM		313	32	X:T	
204	42	STO		259	15	15		314	05	5	
205	14	14		260	92	RTN		315	98	ADV	
206	75	-		261	76	LBL		316	99	PRT	
207	24	CE		262	18	C'		317	32	X:T	
208	65	X		263	32	X:T		318	99	PRT	
209	43	RCL		264	03	3		319	65	X	
210	04	04		265	98	ADV		<div>MERGED CODES</div> <div><div>62</div><div>72</div><div>83</div></div> <div><div>63</div><div>73</div><div>84</div></div> <div><div>64</div><div>74</div><div>92</div></div>			
211	55	+		266	99	PRT					
212	01	1		267	32	X:T					
213	08	8		268	58	FIX					
214	00	0		269	03	03		TEXAS INSTRUMENTS INCORPORATED			

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OF 1000 C-47

TITLE THERMALPAGE 3 OF 3TI Programmable
Coding Form 

PROGRAMMER _____

DATE _____

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
320	43	RCL		375	98	ADV		430	12	B	
321	03	03		376	99	PRT		431	93	.	
322	99	PRT		377	85	+		432	04	4	
323	95	=		378	02	2		433	05	5	
324	58	FIX		379	07	7		434	13	C	
325	03	03		380	03	3		435	16	R	
326	99	PRT		381	95	=		436	93	.	
327	98	ADV		382	33	X2		437	04	4	
328	22	INV		383	33	X2		438	05	5	
329	58	FIX		384	49	PRD		439	12	B	
330	42	STD		385	19	19		440	93	.	
331	19	19		386	01	1		441	01	1	
332	44	SUM		387	06	6		442	02	2	
333	20	20		388	42	STD		443	02	2	
334	93	.		389	02	02		444	13	C	
335	00	0		390	71	SBR		445	17	B	
336	02	2		391	34	FX		446	93	.	
337	05	5		392	71	SBR		447	04	4	
338	87	IFF		393	34	FX		448	05	5	
339	00	00		394	71	SBR		449	18	C	
340	03	03		395	34	FX		450	93	.	
341	44	44		396	52	EE		451	08	8	
342	71	SBR		397	58	FIX		452	02	2	
343	86	STF		398	02	02		453	12	B	
344	99	PRT		399	71	SBR		454	93	.	
345	49	PRD		400	00	00		455	08	8	
346	19	19		401	04	04		456	13	C	
347	85	+		402	98	ADV		457	19	D	
348	01	1		403	98	ADV		458	93	.	
349	95	=		404	03	3		459	08	8	
350	49	PRD		405	69	DP		460	76	LBL	
351	20	20		406	17	17		461	43	RCL	
352	05	5		407	08	8		462	32	XIT	
353	93	.		408	22	INV		463	93	.	
354	06	6		409	90	LST		464	00	0	
355	06	6		410	04	4		465	05	5	
356	09	9		411	69	DP		466	42	STD	
357	07	7		412	17	17		467	07	07	
358	52	EE		413	92	RTN		468	04	4	
359	08	8		414	76	LBL		469	05	5	
360	94	+/-		415	44	SUM		470	38	SIN	
361	22	INV		416	04	4		471	12	B	
362	52	EE		417	04	4		472	13	C	
363	49	PRD		418	04	4		473	05	5	
364	19	19		419	71	SBR		474	00	0	
365	49	PRD		420	32	XIT		475	14	D	
366	20	20		421	11	A		476	32	XIT	
367	05	5		422	93	.		477	15	E	
368	00	0		423	09	9		478	92	RTN	
369	87	IFF		424	01	1		479	00	0	
370	00	00		425	42	STD					
371	03	03		426	07	07					
372	75	75		427	93	.					
373	43	RCL		428	07	7					
374	04	04		429	08	8					

MERGED CODES

62	72	83
63	73	84
64	74	92

TEXAS INSTRUMENTS
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TITLE TEMPERATUREPAGE 1 OF 4

TI Programmable



PROGRAMMER _____

DATE _____

Coding Form

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LEL		055	43	RCL		110	02	C2	
001	43	RCL		056	32	32		111	75	-	
002	85	+		057	58	FIX		112	09	9	
003	43	RCL		058	01	C1		113	00	C	
004	13	13		059	99	PRT		114	95	=	
005	95	=		060	92	RTN		115	50	I>I	
006	65	*		061	87	IFF		116	42	STD	
007	43	RCL		062	06	C6		117	35	35	
008	14	14		063	00	C0		118	87	IFF	
009	55	+		064	79	79		119	04	C4	
010	03	3		065	43	RCL		120	01	C1	
011	06	6		066	30	30		121	51	51	
012	00	C		067	71	SER		122	87	IFF	
013	95	=		068	00	C0		123	06	C6	
014	58	FIX		069	89	89		124	01	C1	
015	02	C2		070	39	C03		125	51	51	
016	52	EE		071	65	*		126	06	6	
017	22	INV		072	93	3		127	03	3	
018	52	EE		073	03	3		128	07	7	
019	76	LEL		074	06	6		129	02	2	
020	89	+		075	85	+		130	42	STD	
021	42	STD		076	01	1		131	01	C1	
022	37	37		077	95	=		132	85	+	
023	71	SER		078	65	*		133	43	RCL	
024	03	C3		079	43	RCL		134	12	12	
025	94	94		080	31	C1		135	95	=	
026	43	RCL		081	95	=		136	42	STD	
027	07	07		082	58	FIX		137	06	C6	
028	32	XIT		083	00	C0		138	36	PGM	
029	43	RCL		084	52	EE		139	11	11	
030	37	37		085	22	INV		140	10	E'	
031	77	GE		086	52	EE		141	36	PGM	
032	89	+		087	99	PRT		142	11	11	
033	42	STD		088	92	RTN		143	15	E	
034	07	07		089	65	*		144	09	9	
035	71	SER		090	03	3		145	00	C	
036	03	C3		091	06	6		146	75	-	
037	95	95		092	00	C		147	43	RCL	
038	92	RTN		093	55	+		148	05	C5	
039	43	RCL		094	43	RCL		149	95	=	
040	30	30		095	14	14		150	50	I>I	
041	22	INV		096	75	-		151	42	STD	
042	58	FIX		097	43	RCL		152	34	C4	
043	98	RIV		098	13	13		153	92	RTN	
044	98	RIV		099	87	IFF		154	43	RCL	
045	99	PRT		100	05	C5		155	30	30	
046	87	IFF		101	01	C1		156	85	+	
047	04	C4		102	07	C7		157	43	RCL	
048	00	C0		103	75	-		158	07	C7	
049	55	55		104	01	1		159	95	=	
050	71	SER		105	08	8					
051	00	C0		106	00	C					
052	61	61		107	95	=					
053	42	STD		108	50	I>I					
054	36	36		109	42	STD					

MERGED CODES

62	72	82	92
63	73	83	93
64	74	84	94

TEXAS INSTRUMENTS
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TITLE TEMPERATUREPAGE 2 OF 4TI Programmable
Coding Form

PROGRAMMER _____

DATE _____

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
160	55	+		215	32	32		270	78	I+	
161	02	2		216	85	+		271	43	RCL	
162	71	SER		217	43	RCL		272	34	34	
163	00	00		218	33	33		273	32	XIT	
164	89	89		219	54	)		274	69	OF	
165	87	IFF		220	55	+		275	20	20	
166	04	C4		221	02	2		276	73	RC*	
167	01	C1		222	54	)		277	00	00	
168	93	93		223	42	STO		278	78	I+	
169	43	RCL		224	35	35		279	53	+	
170	15	15		225	33	X2		280	69	OF	
171	85	+		226	33	X2		281	12	12	
172	93	.		227	95	=		282	85	+	
173	03	3		228	65	x		283	32	XIT	
174	06	6		229	06	6		284	65	x	
175	65	x		230	00	0		285	43	RCL	
176	43	RCL		231	55	+		286	35	35	
177	34	34		232	36	PCM		287	95	=	
178	39	CC8		233	01	C1		288	92	RTN	
179	65	x		234	71	SER		289	76	LEL	
180	43	RCL		235	25	CLR		290	11	11	
181	16	16		236	53	(		291	42	STO	
182	87	IFF		237	53	(		292	30	30	
183	06	C6		238	53	(		293	59	INT	
184	01	C1		239	43	RCL		294	42	STO	
185	88	88		240	35	35		295	07	07	
186	43	RCL		241	75	-		296	69	OF	
187	15	15		242	07	7		297	27	27	
188	95	=		243	03	3		298	43	RCL	
189	65	x		244	54	)		299	30	30	
190	43	RCL		245	55	+		300	92	RTN	
191	31	31		246	02	2		301	76	LEL	
192	85	+		247	05	5		302	12	12	
193	43	RCL		248	54	)		303	42	STO	
194	18	18		249	59	INT		304	31	31	
195	87	IFF		250	42	STO		305	92	RTN	
196	06	C6		251	00	00		306	76	LEL	
197	02	C2		252	65	x		307	18	C1	
198	01	C1		253	02	2		308	85	+	
199	43	RCL		254	05	5		309	02	2	
200	17	17		255	42	STO		310	07	7	
201	65	x		256	34	34		311	03	3	
202	43	RCL		257	85	+		312	95	=	
203	35	35		258	01	1		313	76	LEL	
204	39	CC8		259	07	7		314	13	C1	
205	85	+		260	44	SUM		315	42	STO	
206	43	RCL		261	00	00		316	32	32	
207	19	19		262	07	7		317	42	STO	
208	75	-		263	03	3		318	33	33	
209	43	RCL		264	54	)		319	92	RTN	
210	20	20		265	44	SUM		MERGED CODES 62 <input type="checkbox"/> 63 <input type="checkbox"/> 64 <input type="checkbox"/> 72 <input type="checkbox"/> 73 <input type="checkbox"/> 74 <input type="checkbox"/> 83 <input type="checkbox"/> 84 <input type="checkbox"/> 92 <input type="checkbox"/>			
211	65	x		266	34	34					
212	53	+		267	32	XIT					
213	53	+		268	73	RC*					
214	43	RCL		269	00	00		TEXAS INSTRUMENTS INCORPORATED			

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TITLE TEMPERATUREPAGE 3 OF 4TI Programmable
Coding Form

PROGRAMMER _____

DATE _____

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
320	22	INV		375	01	1		430	97	97	
321	87	IFF		376	95	=		431	43	RCL	
322	04	C4		377	32	XIT		432	33	33	
323	03	C3		378	43	RCL		433	75	-	
324	26	26		379	07	C7		434	43	RCL	
325	94	+/-		380	77	GE		435	32	32	
326	85	+		381	03	C3		436	95	=	
327	43	RCL		382	91	91		437	50	I×I	
328	32	32		383	71	SER		438	32	XIT	
329	95	=		384	04	04		439	02	2	
330	42	STD		385	45	45		440	05	5	
331	33	33		386	02	2		441	22	INV	
332	86	STF		387	05	5		442	77	GE	
333	07	C7		388	61	GTO		443	03	C3	
334	71	SER		389	03	C3		444	20	20	
335	01	C1		390	20	20		445	43	RCL	
336	54	54		391	32	XIT		446	30	30	
337	35	1×X		392	42	STD		447	59	INT	
338	65	*		393	07	C7		448	85	+	
339	53	.		394	22	INV		449	01	1	
340	43	RCL		395	86	STF		450	95	=	
341	33	33		396	07	C7		451	48	EXC	
342	75	-		397	71	SER		452	07	C7	
343	43	RCL		398	01	01		453	58	FIX	
344	32	32		399	54	54		454	03	C3	
345	54	)		400	65	*		455	32	EE	
346	85	+		401	53	(		456	22	INV	
347	43	RCL		402	43	RCL		457	32	EE	
348	30	30		403	07	C7		458	22	INV	
349	85	+		404	75	-		459	58	FIX	
350	32	XIT		405	43	RCL		460	98	RTV	
351	43	RCL		406	30	30		461	99	PRT	
352	07	C7		407	54	)		462	87	IFF	
353	95	=		408	85	+		463	07	C7	
354	55	+		409	43	RCL		464	04	04	
355	02	2		410	32	32		465	68	68	
356	95	=		411	85	+		466	69	DP	
357	48	EXC		412	32	XIT		467	27	27	
358	07	C7		413	43	RCL		468	75	-	
359	75	-		414	33	33		469	48	EXC	
360	93	.		415	95	=		470	30	30	
361	00	0		416	55	+		471	95	=	
362	00	0		417	02	2		472	87	IFF	
363	00	0		418	95	=		473	04	04	
364	05	5		419	48	EXC		474	04	04	
365	32	XIT		420	33	33		475	93	93	
366	95	=		421	75	-		476	32	XIT	
367	50	I×I		422	93	.		477	71	SER	
368	77	GE		423	00	0		478	00	00	
369	03	C3		424	05	5		479	61	61	
370	32	32		425	32	XIT					
371	43	RCL		426	95	=					
372	30	30		427	50	I×I					
373	59	INT		428	77	GE					
374	85	+		429	03	C3					

MERGED CODES

62	63	64	72	73	74	83	84	92
STD	STD	STD	STD	STD	STD	STD	STD	STD

TEXAS INSTRUMENTS
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TI-24191

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TITLE TEMPERATUREPAGE 4 OF 4TI Programmable
Coding Form 

PROGRAMMER _____

DATE _____

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
480	85	+		535	42	STD		590	42	STD	
481	48	END		536	39	39		591	38	38	
482	36	36		537	22	INV		592	43	RCL	
483	95	=		538	86	STF		593	39	39	
484	55	+		539	04	04		594	55	+	
485	02	2		540	86	STF		595	43	RCL	
486	95	=		541	05	05		596	37	37	
487	32	XIT		542	22	INV		597	95	=	
488	65	*		543	86	STF		598	58	FIX	
489	32	XIT		544	06	06		599	01	01	
490	95	=		545	71	SER		600	52	EE	
491	44	SUM		546	00	00		601	22	INV	
492	38	38		547	39	39		602	52	EE	
493	43	RCL		548	25	CLR		603	99	PFT	
494	33	33		549	71	SER		604	42	STD	
495	58	FIX		550	43	RCL		605	39	39	
496	01	01		551	86	STF		606	86	STF	
497	52	EE		552	06	06		607	04	04	
498	22	INV		553	09	9		608	71	SER	
499	52	EE		554	00	0		609	00	00	
500	99	PFT		555	71	SER		610	39	39	
501	85	+		556	43	RCL		611	02	2	
502	48	END		557	01	1		612	07	7	
503	32	32		558	08	8		613	00	0	
504	95	=		559	00	0		614	71	SER	
505	87	IFF		560	71	SER		615	43	RCL	
506	04	04		561	43	RCL		616	43	RCL	
507	05	05		562	22	INV		617	14	14	
508	16	16		563	86	STF		618	71	SER	
509	55	+		564	05	05		619	89	8	
510	02	2		565	22	INV		620	76	LEL	
511	65	*		566	86	STF		621	14	D	
512	32	XIT		567	06	06		622	22	INV	
513	95	=		568	01	1		623	58	FIX	
514	44	SUM		569	08	8		624	03	3	
515	39	39		570	00	0		625	69	OP	
516	92	RTN		571	85	+		626	17	17	
517	76	LEL		572	43	RCL		627	98	ADV	
518	10	E		573	13	13		628	98	ADV	
519	25	CLR		574	71	SER		629	98	ADV	
520	22	INV		575	43	RCL		630	08	8	
521	86	STF		576	43	RCL		631	22	INV	
522	05	05		577	38	38		632	90	LST	
523	22	INV		578	55	+		633	04	4	
524	86	STF		579	43	RCL		634	69	OP	
525	06	06		580	37	37		635	17	17	
526	71	SER		581	95	=		636	92	RTN	
527	06	06		582	58	FIX		637	00	0	
528	06	06		583	00	00		638	00	0	
529	76	LEL		584	52	EE		639	00	0	
530	15	E		585	22	INV					
531	25	CLR		586	52	EE					
532	11	F		587	98	ADV					
533	42	STD		588	98	ADV					
534	38	38		589	99	PFT					










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MERGED CODES
62 ☐ 72 ☐ 83 ☐
63 ☐ 73 ☐ 84 ☐
64 ☐ 74 ☐ 92 ☐TEXAS INSTRUMENTS
INCORPORATED

TI-24181


TITLE MAIN BUS PAGE 1 OF 2
 PROGRAMMER _____ DATE _____

TI Programmable
Coding Form 

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LBL		055	55	+		110	43	RCL	
001	16	A'		056	02	2		111	11	11	
002	42	STD		057	95	=		112	59	INT	
003	23	23		058	42	STD		113	55	+	
004	92	RTN		059	28	28		114	01	1	
005	76	LBL		060	92	RTN		115	52	EE	
006	17	B'		061	76	LBL		116	07	7	
007	42	STD		062	10	E'		117	22	INV	
008	24	24		063	65	X		118	52	EE	
009	92	RTN		064	43	RCL		119	85	+	
010	76	LBL		065	48	48		120	43	RCL	
011	18	C'		066	65	X		121	11	11	
012	42	STD		067	43	RCL		122	22	INV	
013	25	25		068	49	49		123	59	INT	
014	92	RTN		069	95	=		124	95	=	
015	76	LBL		070	42	STD		125	17	B'	
016	25	CLR		071	29	29		126	92	RTN	
017	42	STD		072	92	RTN		127	76	LBL	
018	26	26		073	76	LBL		128	44	SUM	
019	92	RTN		074	33	X ²		129	93	.	
020	76	LBL		075	43	RCL		130	01	1	
021	13	C		076	49	49		131	02	2	
022	42	STD		077	65	X		132	02	2	
023	27	27		078	43	RCL		133	76	LBL	
024	92	RTN		079	30	30		134	45	YX	
025	76	LBL		080	85	+		135	42	STD	
026	22	INV		081	99	PRT		136	16	16	
027	42	STD		082	33	X ²		137	93	.	
028	48	48		083	99	PRT		138	04	4	
029	92	RTN		084	44	SUM		139	07	7	
030	76	LBL		085	26	26		140	09	9	
031	23	LNK		086	92	RTN		141	42	STD	
032	42	STD		087	76	LBL		142	18	18	
033	49	49		088	12	B		143	12	B	
034	92	RTN		089	43	RCL		144	05	5	
035	76	LBL		090	08	08		145	07	7	
036	24	CE		091	59	INT		146	05	5	
037	42	STD		092	65	X		147	03	3	
038	50	50		093	43	RCL		148	42	STD	
039	92	RTN		094	08	08		149	25	25	
040	76	LBL		095	22	INV		150	01	1	
041	11	A		096	59	INT		151	06	6	
042	22	INV		097	55	+		152	09	9	
043	52	EE		098	01	1		153	01	1	
044	22	INV		099	52	EE		154	01	1	
045	58	FIX		100	05	5		155	06	6	
046	06	6		101	95	=		156	42	STD	
047	69	DP		102	58	FIX		157	26	26	
048	17	17		103	03	03		158	02	2	
049	25	CLR		104	52	EE		159	93	.	
050	92	RTN		105	22	INV		MERGED CODES 62  72  83  63  73  84  64  74  92 			
051	76	LBL		106	52	EE					
052	15	E		107	22	INV					
053	43	RCL		108	58	FIX					
054	50	50		109	16	A'		TEXAS INSTRUMENTS INCORPORATED			

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TITLE MAIN BUS PAGE 2 OF 2 TI Programmable 
 PROGRAMMER _____ DATE _____ Coding Form

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
160	06	6		215	55	+					
161	00	0		216	04	4					
162	03	3		217	75	-					
163	52	EE		218	01	1					
164	08	8		219	95	=					
165	94	+/-		220	42	STD					
166	42	STD		221	01	01					
167	27	27		222	06	6					
168	02	2		223	85	+					
169	04	4		224	98	ADV					
170	42	STD		225	98	ADV					
171	28	28		226	99	PRT					
172	06	6		227	33	X ²					
173	00	0		228	99	PRT					
174	00	0		229	42	STD					
175	42	STD		230	26	26					
176	29	29		231	29	CP					
177	76	LBL		232	43	RCL					
178	43	RCL		233	01	01					
179	11	A		234	67	EQ					
180	42	STD		235	34	FX					
181	12	12		236	76	LBL					
182	42	STD		237	32	XIT					
183	13	13		238	71	SBR					
184	42	STD		239	33	X ²					
185	14	14		240	44	SUM					
186	42	STD		241	26	26					
187	15	15		242	97	DSZ					
188	42	STD		243	01	01					
189	17	17		244	32	XIT					
190	42	STD		245	76	LBL					
191	19	19		246	34	FX					
192	42	STD		247	71	SBR					
193	21	21		248	33	X ²					
194	42	STD		249	25	CLR					
195	22	22		250	43	RCL					
196	03	3		251	26	26					
197	69	OP		252	58	FIX					
198	17	17		253	00	00					
199	98	ADV		254	52	EE					
200	98	ADV		255	22	INV					
201	08	8		256	52	EE					
202	22	INV		257	22	INV					
203	90	LST		258	58	FIX					
204	11	A		259	98	ADV					
205	92	RTN		260	99	PRT					
206	76	LBL		261	42	STD					
207	19	D'		262	26	26					
208	42	STD		263	92	RTN					
209	30	30									
210	76	LBL									
211	14	D									
212	11	A									
213	42	RCL									
214	50	50									

MERGED CODES			
62	72	83	
63	73	84	
64	74	92	

TEXAS INSTRUMENTS
INCORPORATED

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TITLE SOLAR CELL PAGE 1 OF 3

PROGRAMMER _____ DATE _____

TI Programmable
Coding Form 

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LBL		055	00	0		110	22	INV	
001	22	INV		056	95	=		111	54	/	
002	01	1		057	72	ST*		112	58	FIX	
003	00	0		058	03	03		113	03	03	
004	00	0		059	92	RTN		114	99	PRT	
005	00	0		060	76	LBL		115	65	*	
006	92	RTN		061	14	D		116	53	(
007	76	LBL		062	16	R'		117	43	RCL	
008	11	R		063	17	B'		118	31	31	
009	42	STD		064	76	LBL		119	22	INV	
010	12	12		065	15	E		120	59	INT	
011	92	RTN		066	07	7		121	65	*	
012	76	LBL		067	18	C'		122	01	1	
013	12	8		068	76	LBL		123	00	0	
014	42	STD		069	13	C		124	54)	
015	14	14		070	98	ADV		125	99	PRT	
016	92	RTN		071	43	RCL		126	54	/	
017	76	LBL		072	14	14		127	58	FIX	
018	16	R'		073	33	X²		128	00	00	
019	42	STD		074	33	X²		129	52	EE	
020	01	01		075	75	-		130	22	INV	
021	92	RTN		076	53	(		131	52	EE	
022	76	LBL		077	53	(		132	99	PRT	
023	17	B'		078	71	SBR		133	42	STD	
024	42	STD		079	03	03		134	13	13	
025	02	02		080	26	26		135	75	-	
026	92	RTN		081	65	*		136	42	STD	
027	76	LBL		082	43	RCL		137	17	17	
028	19	D'		083	16	16		138	43	RCL	
029	42	STD		084	54	)		139	09	09	
030	16	16		085	52	EE		140	59	INT	
031	92	RTN		086	22	INV		141	55	+	
032	76	LBL		087	52	EE		142	71	SBR	
033	10	E'		088	98	ADV		143	22	INV	
034	42	STD		089	98	ADV		144	65	*	
035	18	18		090	99	PRT		145	43	RCL	
036	92	RTN		091	65	*		146	12	12	
037	76	LBL		092	43	RCL		147	54)	
038	18	C'		093	09	09		148	55	+	
039	85	+		094	22	INV		149	43	RCL	
040	03	3		095	59	INT		150	14	14	
041	01	1		096	65	*		151	58	FIX	
042	95	=		097	53	(		152	01	01	
043	42	STD		098	43	RCL		153	99	PRT	
044	03	03		099	12	12		154	43	RCL	
045	43	RCL		100	58	FIX		155	20	20	
046	01	01		101	00	00		156	95	=	
047	65	*		102	99	PRT		157	34	FX	
048	71	SBR		103	65	*		158	34	FX	
049	22	INV		104	53	(		159	52	EE	
050	85	+		105	43	RCL					
051	43	RCL		106	31	31					
052	02	02		107	59	INT					
053	55	+		108	55	+					
054	01	1		109	71	SBR					

62	63	64	72	73	74	83	84	92
62	63	64	72	73	74	83	84	92
62	63	64	72	73	74	83	84	92

TEXAS INSTRUMENTS
INCORPORATED

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PAGE 10

TITLE SOLAR CELLPAGE 2 OF 3TI Programmable
Coding Form 

PROGRAMMER _____

DATE _____

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
150	22	INV		215	08	8		270	24	24	
151	52	EE		216	44	SUM		271	65	*	
152	39	PRT		217	00	00		272	43	RCL	
153	42	STD		218	73	RC+		273	25	25	
154	15	15		219	00	00		274	65	*	
155	85	+		220	42	STD		275	43	RCL	
156	02	2		221	21	21		276	26	26	
157	95	=		222	69	OP		277	65	*	
158	35	-		223	20	20		278	43	RCL	
159	02	2		224	73	RC+		279	27	27	
160	05	5		225	00	00		280	55	+	
161	42	STD		226	71	SBR		281	43	RCL	
162	07	07		227	04	04		282	28	28	
163	85	+		228	32	32		283	54	*	
164	59	INT		229	55	+		284	34	FX	
165	49	PRD		230	01	1		285	55	+	
166	07	07		231	00	0		286	43	RCL	
167	03	3		232	85	+		287	19	19	
168	05	5		233	43	RCL		288	99	PRT	
169	95	=		234	32	32		289	55	+	
170	42	STD		235	59	INT		290	43	RCL	
171	00	00		236	95	=		291	29	29	
172	71	SBR		237	42	STD		292	95	=	
173	03	03		238	32	32		293	52	EE	
174	58	58		239	71	SBR		294	22	INV	
175	42	STD		240	03	03		295	52	EE	
176	21	21		241	27	27		296	22	INV	
177	69	OP		242	65	*		297	59	FIX	
178	20	20		243	43	RCL		298	16	R	
179	71	SBR		244	18	18		299	17	B	
180	03	03		245	95	=		300	92	RTN	
181	58	58		246	52	EE		301	69	OP	
182	71	SBR		247	22	INV		302	21	21	
183	04	04		248	52	EE		303	53	*	
184	32	32		249	42	STD		304	73	RC+	
185	65	*		250	19	19		305	01	01	
186	71	SBR		251	01	1		306	22	INV	
187	22	INV		252	75	-		307	59	INT	
188	37	+		253	53	*		308	65	*	
189	32	XIT		254	53	*		309	01	1	
190	43	RCL		255	43	RCL		310	00	0	
191	32	32		256	17	17		311	54	*	
192	22	INV		257	65	*		312	87	IFF	
193	59	INT		258	43	RCL		313	00	00	
194	95	=		259	23	23		314	03	03	
195	48	ENC		260	54	*		315	24	24	
196	32	32		261	52	EE		316	53	*	
197	59	INT		262	22	INV		317	73	RC+	
198	22	INV		263	52	EE		318	01	01	
199	67	EO		264	42	STD		319	53	INT	
200	00	00		265	17	17					
201	71	71		266	98	ADV					
202	71	SBR		267	99	PRT					
203	03	03		268	55	+					
204	26	26		269	43	RCL					

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MERGED CODES											
62	STO	72	STO	82	STO	92	STO	02	STO	12	STO
63	STO	73	STO	83	STO	93	STO	03	STO	13	STO
64	STO	74	STO	84	STO	94	STO	04	STO	14	STO

TEXAS INSTRUMENTS
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TITLE SOLAR CELL

PAGE 3 OF 3

TI Programmable



PROGRAMMER

DATE

Coding Form

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
320	55	-		375	01	01		430	95	=	
321	71	SBR		376	73	RC+		431	93	RTN	
322	22	INV		377	00	00		432	42	STO	
323	54	?		378	23	INV		433	22	22	
324	99	FRT		379	59	INT		434	36	PGM	
325	92	RTN		380	65	X		435	01	01	
326	23	INV		381	01	1		436	71	SBR	
327	86	STF		382	00	0		437	25	CLR	
328	00	00		383	95	=		438	43	RCL	
329	03	3		384	76	1+		439	07	07	
330	01	1		385	09	9		440	75	-	
331	16	A'		386	06	6		441	02	2	
332	01	1		387	00	5		442	95	=	
333	00	0		388	87	IFF		443	32	NIT	
334	17	B'		389	01	01		444	43	RCL	
335	56	FIN		390	03	03		445	21	21	
336	03	03		391	96	96		446	78	1+	
337	98	ADV		392	02	2		447	43	RCL	
338	53	?		393	04	4		448	07	07	
339	71	SBR		394	01	1		449	85	+	
340	03	03		395	06	6		450	02	2	
341	01	01		396	32	NIT		451	03	3	
342	65	X		397	73	RC+		452	95	=	
343	97	DSZ		398	00	00		453	32	NIT	
344	02	02		399	59	INT		454	43	RCL	
345	03	03		400	55	+		455	32	22	
346	39	39		401	43	RCL		456	78	2+	
347	09	9		402	30	30		457	69	OP	
348	16	A'		403	95	=		458	12	12	
349	71	SBR		404	42	STO		459	85	+	
350	03	03		405	22	22		460	32	NIT	
351	01	01		406	23	INV		461	65	X	
352	54	?		407	59	INT		462	43	RCL	
353	52	EE		408	87	IFF		463	15	15	
354	22	INV		409	01	01		464	95	=	
355	52	EE		410	04	04		465	58	FIN	
356	99	PRT		411	13	13		466	03	03	
357	92	RTN		412	43	RCL		467	52	EE	
358	36	PGM		413	23	23		468	22	INV	
359	01	01		414	59	INT		469	52	EE	
360	71	SBR		415	55	-		470	92	RTN	
361	25	CLR		416	43	RCL		471	00	0	
362	01	1		417	30	30		472	00	0	
363	03	2		418	65	X		473	00	0	
364	05	5		419	01	1		474	00	0	
365	03	3		420	00	0		475	00	0	
366	32	NIT		421	95	=		476	00	0	
367	43	RCL		422	78	1+		477	00	0	
368	13	13		423	69	OP		478	00	0	
369	23	INV		424	12	12		479	00	0	
370	77	OE		425	85	+		MERGED CODES 62 72 82 92 63 73 83 93 64 74 84 94			
371	03	03		426	32	NIT					
372	74	74		427	65	X					
373	23	INV		428	43	RCL					
374	86	STF		429	13	13		TEXAS INSTRUMENTS INCORPORATED			

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DATA BASE
FOR
SOLAR CELL
PROGRAM

10000.	30
1017.087	31
717.0759	32
965.1	33
993.0993	34
999.0999	35
999.0999	36
999.0999	37
961.0957	38
988.0988	39
1000.1	40
800.1	41
23100935.1 290	42
22900930.1 280	43
22300905.1245	44
21400865.1 295	45
20050812.1120	46
17900725.1000	47
15650635.0 775	48
13450545.0 750	49
10900442.0610	50
1.455	51
1.395	52
1.32	53
1.23	54
1.125	55
1.	56
0.88	57
0.745	58
0.615	59

TITLE SOLAR ARRAY

PAGE 1 OF 3

TI Programmable
Coding Form

PROGRAMMER _____

DATE _____

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LBL		055	30	TAN		110	05	5	
001	11	A		056	69	OP		111	54	>	
002	42	STD		057	21	21		112	19	D'	
003	17	17		058	64	PD*		113	16	A'	
004	92	RTN		059	01	01		114	92	RTN	
005	76	LBL		060	97	DSZ		115	76	LBL	
006	12	B		061	02	02		116	13	C	
007	42	STD		062	30	TAN		117	98	ADV	
008	19	19		063	92	RTN		118	98	ADV	
009	92	RTN		064	76	LBL		119	43	RCL	
010	76	LBL		065	38	SIN		120	17	17	
011	16	A'		066	71	SBR		121	32	X:T	
012	32	X:T		067	39	COS		122	04	4	
013	03	3		068	98	ADV		123	03	3	
014	00	0		069	00	0		124	18	C'	
015	18	C'		070	76	LBL		125	43	RCL	
016	92	RTN		071	22	INV		126	19	19	
017	76	LBL		072	42	STD		127	32	X:T	
018	19	D'		073	00	00		128	04	4	
019	58	FIX		074	43	RCL		129	02	2	
020	40	IND		075	17	17		130	13	C'	
021	00	00		076	65	X		131	43	RCL	
022	52	EE		077	43	RCL		132	51	51	
023	22	INV		078	53	53		133	55	+	
024	52	EE		079	95	=		134	43	RCL	
025	92	RTN		080	19	D'		135	49	49	
026	76	LBL		081	32	X:T		136	55	+	
027	17	B'		082	04	4		137	43	RCL	
028	32	X:T		083	03	3		138	47	47	
029	02	2		084	18	C'		139	55	+	
030	06	6		085	43	RCL		140	43	RCL	
031	02	2		086	29	29		141	19	19	
032	02	2		087	65	X		142	85	+	
033	76	LBL		088	43	RCL		143	01	1	
034	18	C'		089	19	19		144	95	=	
035	22	INV		090	95	=		145	59	INT	
036	58	FIX		091	32	X:T		146	98	ADV	
037	69	OP		092	04	4		147	32	X:T	
038	04	04		093	02	2		148	03	3	
039	32	X:T		094	18	C'		149	06	6	
040	69	OP		095	92	RTN		150	18	C'	
041	06	06		096	76	LBL		151	42	STD	
042	92	RTN		097	37	P/R		152	29	29	
043	76	LBL		098	85	+		153	32	X:T	
044	39	COS		099	43	RCL		154	05	5	
045	32	X:T		100	43	43		155	77	GE	
046	05	5		101	65	X		156	28	LOG	
047	02	2		102	02	2		157	22	INV	
048	42	STD		103	85	+		158	76	LBL	
049	01	01		104	02	2		159	28	LOG	
050	05	5		105	42	STD					
051	42	STD		106	00	00					
052	02	02		107	93	.					
053	32	X:T		108	00	0					
054	76	LBL		109	00	0					

MERGED CODES							
62	72	83	94	73	84	95	96
63	74	85	97	75	86	98	99
64	76	87	99	77	88	99	99

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TITLE SOLAR ARRAYPAGE 2 OF 3TI Programmable
Coding Form

PROGRAMMER _____

DATE _____

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
160	86	STF		215	65	X		270	22	INV	
161	00	00		216	02	2		271	52	EE	
162	43	RCL		217	55	+		272	71	SBR	
163	52	52		218	43	RCL		273	37	P/R	
164	55	+		219	44	44		274	42	STD	
165	43	RCL		220	85	+		275	13	13	
166	50	50		221	01	1		276	65	X	
167	55	+		222	95	=		277	53	(
168	43	RCL		223	59	INT		278	43	RCL	
169	49	49		224	65	X		279	14	14	
170	55	+		225	43	RCL		280	65	X	
171	43	RCL		226	44	44		281	43	RCL	
172	48	48		227	95	=		282	08	08	
173	55	+		228	98	ADV		283	22	INV	
174	43	RCL		229	32	X:T		284	59	INT	
175	17	17		230	04	4		285	71	SBR	
176	55	+		231	04	4		286	37	P/R	
177	32	X:T		232	18	C'		287	42	STD	
178	85	+		233	42	STD		288	14	14	
179	01	1		234	13	13		289	95	=	
180	95	=		235	43	RCL		290	19	D'	
181	59	INT		236	14	14		291	32	X:T	
182	32	X:T		237	32	X:T		292	03	3	
183	06	6		238	04	4		293	00	0	
184	03	3		239	05	5		294	07	7	
185	06	6		240	18	C'		295	00	0	
186	03	3		241	43	RCL		296	18	C'	
187	18	C'		242	53	53		297	42	STD	
188	65	X		243	65	X		298	54	54	
189	43	RCL		244	02	2		299	65	X	
190	29	29		245	65	X		300	53	(
191	95	=		246	32	X:T		301	43	RCL	
192	32	X:T		247	01	1		302	11	11	
193	01	1		248	05	5		303	59	INT	
194	05	5		249	18	C'		304	55	+	
195	18	C'		250	42	STD		305	53	(
196	42	STD		251	53	53		306	43	RCL	
197	53	53		252	43	RCL		307	08	08	
198	01	1		253	11	11		308	59	INT	
199	71	SBR		254	22	INV		309	65	X	
200	22	INV		255	59	INT		310	43	RCL	
201	43	RCL		256	95	=		311	08	08	
202	53	53		257	42	STD		312	22	INV	
203	55	+		258	12	12		313	59	INT	
204	04	4		259	53	(		314	54)	
205	00	0		260	43	RCL		315	19	D'	
206	87	IFF		261	13	13		316	54)	
207	00	00		262	65	X		317	19	D'	
208	29	CP		263	43	RCL		318	55	+	
209	04	4		264	08	08		319	03	3	
210	02	2		265	59	INT					
211	76	LBL		266	55	+					
212	29	CP		267	01	1					
213	42	STD		268	52	EE					
214	14	14		269	05	5					

MERGED CODES

62 <input type="checkbox"/>	72 <input type="checkbox"/>	83 <input type="checkbox"/>
63 <input type="checkbox"/>	73 <input type="checkbox"/>	84 <input type="checkbox"/>
64 <input type="checkbox"/>	74 <input type="checkbox"/>	92 <input type="checkbox"/>

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THE QUALITY
OF YOUR QUALITY

TITLE SOLAR ARRAY

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TI Programmable
Coding Form 

PROGRAMMER

DATE

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
320	42	STD		375	43	43		430	56	56	
321	00	00		376	95	=		431	75	-	
322	01	1		377	42	STD		432	01	1	
323	00	0		378	14	14		433	54)	
324	00	0		379	85	+		434	65	x	
325	95	=		380	43	RCL		435	43	RCL	
326	19	D'		381	34	34		436	34	34	
327	85	+		382	95	=		437	85	+	
328	48	EXC		383	42	STD		438	02	2	
329	12	12		384	30	30		439	65	x	
330	19	D'		385	00	0		440	01	1	
331	17	B'		386	98	ADV		441	42	STD	
332	95	=		387	71	SBR		442	00	00	
333	48	EXC		388	22	INV		443	43	RCL	
334	12	12		389	43	RCL		444	33	33	
335	17	B'		390	13	13		445	54)	
336	43	RCL		391	16	A'		446	19	D'	
337	12	12		392	43	RCL		447	16	A'	
338	17	B'		393	14	14		448	42	STD	
339	43	RCL		394	16	A'		449	14	14	
340	47	47		395	43	RCL		450	95	=	
341	49	PRD		396	49	49		451	42	STD	
342	29	29		397	49	PRD		452	57	57	
343	43	RCL		398	29	29		453	02	2	
344	13	13		399	71	SBR		454	71	SBR	
345	75	-		400	39	CDS		455	38	SIN	
346	43	RCL		401	42	STD		456	02	2	
347	43	43		402	56	56		457	71	SBR	
348	95	=		403	00	0		458	38	SIN	
349	65	x		404	98	ADV		459	00	0	
350	43	RCL		405	71	SBR		460	42	STD	
351	46	46		406	22	INV		461	00	00	
352	71	SBR		407	43	RCL		462	43	RCL	
353	39	CDS		408	50	50		463	54	54	
354	42	STD		409	55	+		464	19	D'	
355	55	55		410	04	4		465	42	STD	
356	85	+		411	95	=		466	54	54	
357	43	RCL		412	71	SBR		467	43	RCL	
358	43	43		413	38	SIN		468	57	57	
359	95	=		414	43	RCL		469	19	D'	
360	42	STD		415	30	30		470	42	STD	
361	13	13		416	16	A'		471	15	15	
362	43	RCL		417	43	RCL		472	32	X:T	
363	14	14		418	13	13		473	03	3	
364	75	-		419	16	A'		474	00	0	
365	43	RCL		420	65	x		475	07	7	
366	43	43		421	53	(		476	00	0	
367	95	=		422	43	RCL		477	18	C'	
368	65	x		423	14	14		478	92	RTN	
369	43	RCL		424	65	x		479	00	0	
370	45	45		425	43	RCL					
371	71	SBR		426	56	56					
372	39	CDS		427	85	+					
373	85	+		428	53	(
374	43	RCL		429	43	RCL					

MERGED CODES			
62	72	83	
63	73	84	
64	74	92	

TEXAS INSTRUMENTS
INCORPORATED

DATA BASE
FOR
SOLAR ARRAY
PROGRAM

0.	30
154.	31
.7927135678	32
0.5	33
0.025	34
0.86	35
0.	36
0.	37
0.	38
0.	39
0.	40
0.	41
0.026	42
0.05	43
3.	44
3.	45
5.	46
30.	47
30.	48
4.	49
48.	50
180.	51
480000.	52
0.	53
0.	54
0.	55
0.	56
0.	57
0.	58
0.	59

TITLE WEIGHTPAGE 1 OF 3TI Programmable
Coding Form 

PROGRAMMER _____

DATE _____

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LBL		055	03	3		110	18	C'	
001	16	R'		056	03	3		111	44	SUM	
002	32	XIT		057	07	7		112	59	59	
003	03	3		058	00	0		113	29	CP	
004	03	3		059	00	0		114	43	RCL	
005	01	1		060	00	0		115	48	48	
006	02	2		061	00	0		116	55	+	
007	03	3		062	69	DP		117	43	RCL	
008	01	1		063	03	03		118	47	47	
009	76	LBL		064	98	ADV		119	75	-	
010	18	C'		065	98	ADV		120	01	1	
011	22	INV		066	98	ADV		121	95	=	
012	58	FIX		067	69	DP		122	67	EO	
013	69	DP		068	05	05		123	22	INV	
014	04	04		069	43	RCL		124	85	+	
015	32	XIT		070	45	45		125	03	3	
016	52	FIX		071	55	X		126	05	5	
017	40	IND		072	43	RCL		127	95	=	
018	00	00		073	46	46		128	42	STD	
019	52	EE		074	65	X		129	22	22	
020	22	INV		075	02	2		130	73	RC#	
021	52	EE		076	42	STD		131	22	22	
022	69	DP		077	00	00		132	32	XIT	
023	06	06		078	43	RCL		133	01	1	
024	92	RTN		079	12	12		134	07	7	
025	76	LBL		080	95	=		135	02	2	
026	17	B'		081	98	ADV		136	04	4	
027	32	XIT		082	32	XIT		137	01	1	
028	01	1		083	03	3		138	05	5	
029	04	4		084	00	0		139	00	0	
030	02	2		085	03	3		140	03	3	
031	07	7		086	02	2		141	18	C'	
032	02	2		087	01	1		142	44	SUM	
033	06	6		088	06	6		143	59	59	
034	03	3		089	18	C'		144	76	LBL	
035	07	7		090	42	STD		145	22	INV	
036	61	STD		091	59	59		146	43	RCL	
037	18	C'		092	43	RCL		147	49	49	
038	76	LBL		093	47	47		148	65	X	
039	13	C		094	75	-		149	43	RCL	
040	22	INV		095	01	1		150	50	50	
041	58	FIX		096	95	=		151	55	+	
042	04	4		097	65	X		152	04	4	
043	03	3		098	43	RCL		153	95	=	
044	01	1		099	42	42		154	42	STD	
045	07	7		100	95	=		155	22	22	
046	02	2		101	32	XIT		156	55	X	
047	04	4		102	01	1		157	43	RCL	
048	69	DP		103	07	7		158	59	59	
049	00	00		104	02	2		159	16	R'	
050	59	DP		105	04	4					
051	02	02		106	01	1					
052	02	2		107	05	5					
053	02	2		108	00	0					
054	02	2		109	02	2					

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MERGED CODES							
62	72	82	92	02	12	22	32
63	73	83	93	03	13	23	33
64	74	84	94	04	14	24	34

TEXAS INSTRUMENTS
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TITLE WEIGHTPAGE 2 OF 3

TI Programmable



PROGRAMMER _____

DATE _____

Coding Form

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
160	32	XIT		215	02	2		270	43	RCL	
161	00	0		216	95	=		271	50	50	
162	43	STD		217	32	XIT		272	65	X	
163	00	00		218	01	1		273	43	RCL	
164	32	XIT		219	07	7		274	17	17	
165	95	=		220	03	3		275	55	+	
166	99	ADV		221	01	1		276	43	RCL	
167	16	R'		222	01	1		277	19	19	
168	43	STD		223	06	6		278	55	+	
169	58	58		224	18	C'		279	43	RCL	
170	43	RCL		225	44	SUM		280	29	29	
171	33	33		226	58	58		281	54	+	
172	75	-		227	43	RCL		282	33	X	
173	01	1		228	49	49		283	65	X	
174	95	=		229	75	-		284	43	RCL	
175	65	X		230	01	1		285	27	27	
176	53	X		231	95	=		286	65	X	
177	43	RCL		232	65	X		287	43	RCL	
178	34	34		233	43	RCL		288	25	25	
179	85	+		234	50	50		289	65	X	
180	02	2		235	55	+		290	43	RCL	
181	65	X		236	04	4		291	26	26	
182	43	RCL		237	65	X		292	55	+	
183	43	43		238	43	RCL		293	43	RCL	
184	34	+		239	35	35		294	17	17	
185	65	X		240	95	=		295	65	X	
186	43	RCL		241	32	XIT		296	43	RCL	
187	13	13		242	01	1		297	24	24	
188	65	X		243	07	7		298	95	=	
189	07	7		244	02	2		299	34	FX	
190	93	.		245	04	4		300	58	FIX	
191	05	5		246	01	1		301	00	00	
192	95	=		247	05	5		302	52	EE	
193	32	XIT		248	18	C'		303	22	INV	
194	03	3		249	44	SUM		304	52	EE	
195	00	0		250	58	58		305	65	X	
196	01	1		251	43	RCL		306	04	4	
197	07	7		252	58	58		307	93	.	
198	02	2		253	17	B'		308	01	1	
199	04	4		254	65	X		309	95	=	
200	01	1		255	04	4		310	32	XIT	
201	05	5		256	95	=		311	03	3	
202	18	C'		257	98	ADV		312	00	0	
203	44	SUM		258	17	B'		313	01	1	
204	58	58		259	42	STD		314	04	4	
205	43	RCL		260	58	58		315	18	C'	
206	33	33		261	42	STD		316	44	SUM	
207	65	X		262	22	22		317	22	22	
208	43	RCL		263	43	RCL		318	42	STD	
209	13	13		264	28	28		319	57	57	
210	65	X		265	65	X					
211	07	7		266	53	X					
212	93	.		267	43	RCL					
213	05	5		268	53	53					
214	65	X		269	55	+					

62 ☐ 51 72 ☐ 83 ☐ 92 ☐

63 ☐ 52 73 ☐ 84 ☐ 93 ☐

64 ☐ 53 74 ☐ 85 ☐ 94 ☐

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TITLE WEIGHT PAGE 3 OF 3

PROGRAMMER _____ DATE _____

TI Programmable
Coding Form 

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
320	43	RCL		375	03	3		430	22	INV	
321	14	14		376	02	2		431	58	FIX	
322	55	+		377	03	3		432	01	1	
323	01	1		378	07	7		433	06	6	
324	05	5		379	18	C'		434	01	1	
325	00	0		380	43	RCL		435	03	3	
326	95	=		381	53	53		436	69	DP	
327	45	YX		382	65	X		437	00	00	
328	03	3		383	43	RCL		438	69	DP	
329	65	X		384	17	17		439	02	02	
330	43	RCL		385	95	=		440	03	3	
331	32	32		386	52	EE		441	07	7	
332	65	X		387	22	INV		442	01	1	
333	53	(		388	52	EE		443	03	3	
334	43	RCL		389	42	STD		444	52	EE	
335	57	57		390	21	21		445	06	6	
336	85	+		391	55	+		446	22	INV	
337	43	RCL		392	02	2		447	52	EE	
338	58	58		393	42	STD		448	69	DP	
339	95	=		394	00	00		449	03	03	
340	52	EE		395	43	RCL		450	98	ADV	
341	22	INV		396	15	15		451	98	ADV	
342	52	EE		397	95	=		452	98	ADV	
343	85	+		398	98	ADV		453	98	ADV	
344	53	(		399	32	XIT		454	69	DP	
345	43	RCL		400	04	4		455	05	05	
346	50	50		401	03	3		456	98	ADV	
347	55	+		402	06	6		457	01	1	
348	04	4		403	03	3		458	02	2	
349	08	8		404	03	3		459	22	INV	
350	65	X		405	00	0		460	90	LST	
351	43	RCL		406	07	7		461	92	RTN	
352	31	31		407	00	0		462	00	0	
353	54	)		408	18	C'		463	00	0	
354	52	EE		409	48	EXC		464	00	0	
355	22	INV		410	21	21		465	00	0	
356	52	EE		411	55	+		466	00	0	
357	95	=		412	43	RCL		467	00	0	
358	32	XIT		413	22	22		468	00	0	
359	03	3		414	95	=		469	00	0	
360	06	6		415	98	ADV		470	00	0	
361	03	3		416	32	XIT		471	00	0	
362	07	7		417	04	4		472	00	0	
363	03	3		418	03	3		473	00	0	
364	05	5		419	06	6		474	00	0	
365	18	C'		420	03	3		475	00	0	
366	44	SUM		421	02	2		476	00	0	
367	57	57		422	06	6		477	00	0	
368	44	SUM		423	02	2		478	00	0	
369	22	22		424	02	2		479	00	0	
370	43	RCL		425	18	C'					
371	22	22		426	42	STD					
372	32	XIT		427	22	22					
373	03	3		428	76	LBL					
374	07	7		429	15	E					

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MERGED CODES
 62 72 83
 63 73 84
 64 74 92

TEXAS INSTRUMENTS
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TI-92181

TITLE LCCMPAGE 1 OF 3

TI Programmable



PROGRAMMER _____

DATE _____

Coding Form

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LBL		055	29	CP		110	52	EE	
001	52	EE		056	69	OP		111	95	=	
002	54	)		057	23	23		112	42	STD	
003	58	FIX		058	73	RC+		113	13	13	
004	03	03		059	03	03		114	32	XIT	
005	52	EE		060	65	X		115	92	RTN	
006	22	INV		061	69	OP		116	76	LBL	
007	52	EE		062	22	22		117	13	C	
008	32	INV		063	73	RC#		118	25	CLR	
009	58	FIX		064	02	02		119	22	INV	
010	92	RTN		065	71	SBR		120	58	FIN	
011	76	LBL		066	52	EE		121	98	ADV	
012	37	P/R		067	99	PRT		122	98	ADV	
013	53	(		068	74	SH+		123	98	ADV	
014	53	(		069	00	00		124	05	5	
015	43	RCL		070	97	DSZ		125	03	3	
016	57	57		071	01	01		126	22	INV	
017	85	+		072	29	CP		127	90	LST	
018	43	RCL		073	92	RTN		128	98	ADV	
019	58	58		074	76	LBL		129	98	ADV	
020	85	+		075	17	B'		130	03	3	
021	43	RCL		076	85	+		131	69	OP	
022	59	59		077	04	4		132	17	17	
023	65	X		078	93	.		133	05	5	
024	43	RCL		079	07	7		134	42	STD	
025	25	25		080	03	3		135	03	03	
026	54	)		081	61	GTO		136	04	4	
027	65	X		082	22	INV		137	22	INV	
028	69	OP		083	76	LBL		138	90	LST	
029	21	21		084	12	B		139	06	6	
030	73	RC#		085	85	+		140	69	OP	
031	01	01		086	03	3		141	17	17	
032	71	SBR		087	93	.		142	03	3	
033	52	EE		088	01	1		143	05	5	
034	92	RTN		089	00	0		144	42	STD	
035	76	LBL		090	76	LBL		145	00	00	
036	28	LDG		091	22	INV		146	06	6	
037	42	STD		092	95	=		147	71	SBR	
038	01	01		093	42	STD		148	28	LDG	
039	05	5		094	04	04		149	43	RCL	
040	02	2		095	65	X		150	35	35	
041	42	STD		096	32	XIT		151	99	PRT	
042	02	02		097	01	1		152	65	X	
043	73	RC#		098	93	.		153	02	2	
044	03	03		099	02	2		154	93	.	
045	65	X		100	09	9		155	06	6	
046	04	4		101	09	9		156	07	7	
047	71	SBR		102	09	9		157	71	SBR	
048	52	EE		103	06	6		158	52	EE	
049	98	ADV		104	03	3		159	42	STD	
050	98	ADV		105	02	2					
051	99	PRT		106	52	EE					
052	72	ST+		107	06	6					
053	00	00		108	94	--					
054	76	LBL		109	22	INV					

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TI-24151

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TITLE LCCMPAGE 2 OF 3

TI Programmable



PROGRAMMER _____

DATE _____

Coding Form

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
160	36	36		215	09	9		270	53	(
161	01	1		216	42	STD		271	43	RCL	
162	02	2		217	01	01		272	24	24	
163	42	STD		218	71	SBR		273	65	X	
164	03	03		219	37	P/R		274	93	.	
165	03	3		220	42	STD		275	00	0	
166	07	7		221	42	42		276	07	7	
167	42	STD		222	95	=		277	71	SBR	
168	00	00		223	42	STD		278	53	EE	
169	05	5		224	43	43		279	41	SUM	
170	71	SBR		225	85	+		280	47	47	
171	28	LOG		226	43	RCL		281	54)	
172	43	RCL		227	36	36		282	42	STD	
173	37	37		228	95	=		283	43	48	
174	99	PRT		229	42	STD		284	95	=	
175	85	+		230	44	44		285	42	STD	
176	53	(		231	65	X		286	49	49	
177	24	CE		232	01	1		287	65	X	
178	65	X		233	93	.		288	93	.	
179	93	.		234	01	1		289	03	3	
180	01	1		235	00	0		290	05	5	
181	71	SBR		236	06	6		291	71	SBR	
182	52	EE		237	65	X		292	52	EE	
183	42	STD		238	01	1		293	42	STD	
184	38	38		239	93	.		294	50	50	
185	85	+		240	01	1		295	43	RCL	
186	53	(		241	05	5		296	26	26	
187	42	RCL		242	71	SBR		297	42	STD	
188	18	18		243	52	EE		298	51	51	
189	65	X		244	42	STD		299	65	X	
190	43	RCL		245	45	45		300	01	1	
191	53	53		246	85	+		301	93	.	
192	71	SBR		247	53	(		302	09	9	
193	52	EE		248	71	SBR		303	02	2	
194	42	STD		249	37	P/R		304	71	SBR	
195	39	39		250	42	STD		305	52	EE	
196	85	+		251	46	46		306	42	STD	
197	53	(		252	85	+		307	52	52	
198	43	RCL		253	43	RCL		308	65	X	
199	39	39		254	22	22		309	01	1	
200	65	X		255	44	SUM		310	93	.	
201	93	.		256	46	46		311	01	1	
202	00	0		257	85	+		312	05	5	
203	07	7		258	69	DP		313	71	SBR	
204	71	SBR		259	21	21		314	52	EE	
205	52	EE		260	71	SBR		315	42	STD	
206	42	STD		261	37	P/R		316	53	53	
207	40	40		262	42	STD		317	85	+	
208	85	+		263	47	47		318	53	(
209	43	RCL		264	85	+		319	43	RCL	
210	19	19		265	43	RCL					
211	42	STD		266	24	24					
212	41	41		267	44	SUM					
213	85	+		268	47	47					
214	01	1		269	85	+					

MERGED CODES											
62	63	64	72	73	74	82	83	84	92	93	94
STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD
62	63	64	72	73	74	82	83	84	92	93	94
STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD

TEXAS INSTRUMENTS
INCORPORATED

TI-24181

TITLE LCCM PAGE 3 OF 3

PROGRAMMER _____ DATE _____

TI Programmable
Coding Form 

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
320	27	27		375	05	5					
321	42	STD		376	22	INV					
322	54	54		377	90	LST					
323	85	+		378	92	RTN					
324	43	RCL									
325	28	28									
326	42	STD									
327	55	55									
328	85	+									
329	43	RCL									
330	29	29									
331	42	STD									
332	56	56									
333	54)									
334	42	STD									
335	57	57									
336	95	=									
337	42	STD									
338	58	58									
339	85	+									
340	43	RCL									
341	49	49									
342	85	+									
343	43	RCL									
344	50	50									
345	95	=									
346	42	STD									
347	59	59									
348	76	LBL									
349	14	D									
350	98	ADV									
351	98	ADV									
352	98	ADV									
353	02	2									
354	07	7									
355	01	1									
356	05	5									
357	69	OP									
358	00	00									
359	69	OP									
360	02	02									
361	01	1									
362	05	5									
363	03	3									
364	00	0									
365	52	EE									
366	06	6									
367	22	INV									
368	52	EE									
369	69	OP									
370	03	03									
371	69	OP									
372	05	05									
373	98	ADV									
374	03	3									

MERGED CODES

62	72	83
63	73	84
64	74	92

TEXAS INSTRUMENTS
INCORPORATED

DATA BASE

FOR

LCCM

PROGRAM

0.	00
0.	01
0.	02
0.	03
7.75	04
0.3665	05
.0000003058	06
.0000433167	07
.0012857639	08
0.022421875	09
.0000031583	10
.0000049925	11
0.07775	12
.0000100747	13
.0001848798	14
.0002572917	15
.0102604167	16
.0003639953	17
.0000156013	18
0.945	19
.0000028278	20
.0027517805	21
4.228	22
.0000274403	23
0.18	24
23.	25
0.408	26
2.5	27
146.25	28
11.	29

APPENDIX D

AVERAGE TEMPERATURE VARIATIONS

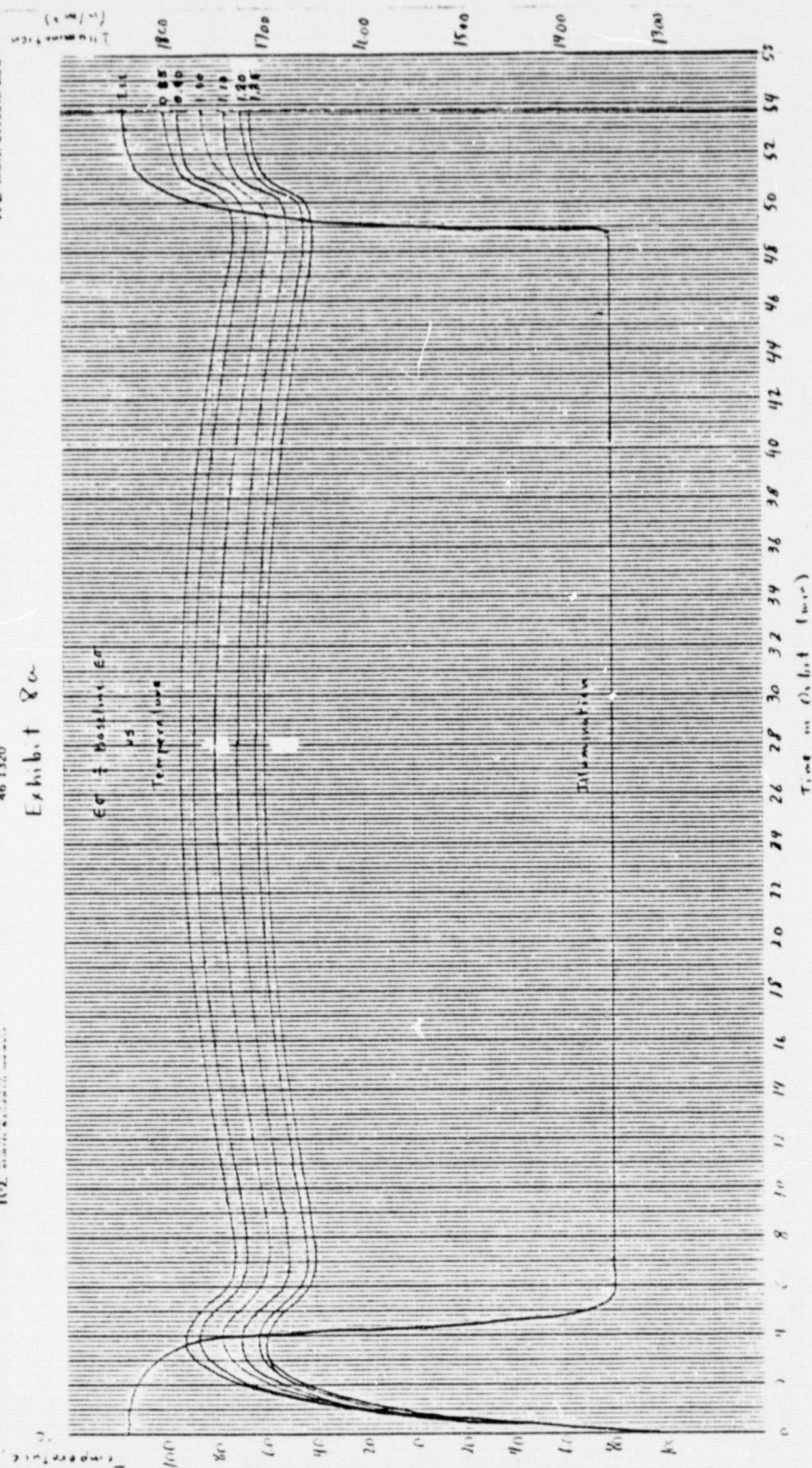
The data in Appendix D consists of

- Sample temperature profiles plotted from data points calculated by temperature subroutine of SACPM program (D-3)
- Average temperature curves showing the effect of various parameters on solar array average operating temperature (D-4 thru D-12)

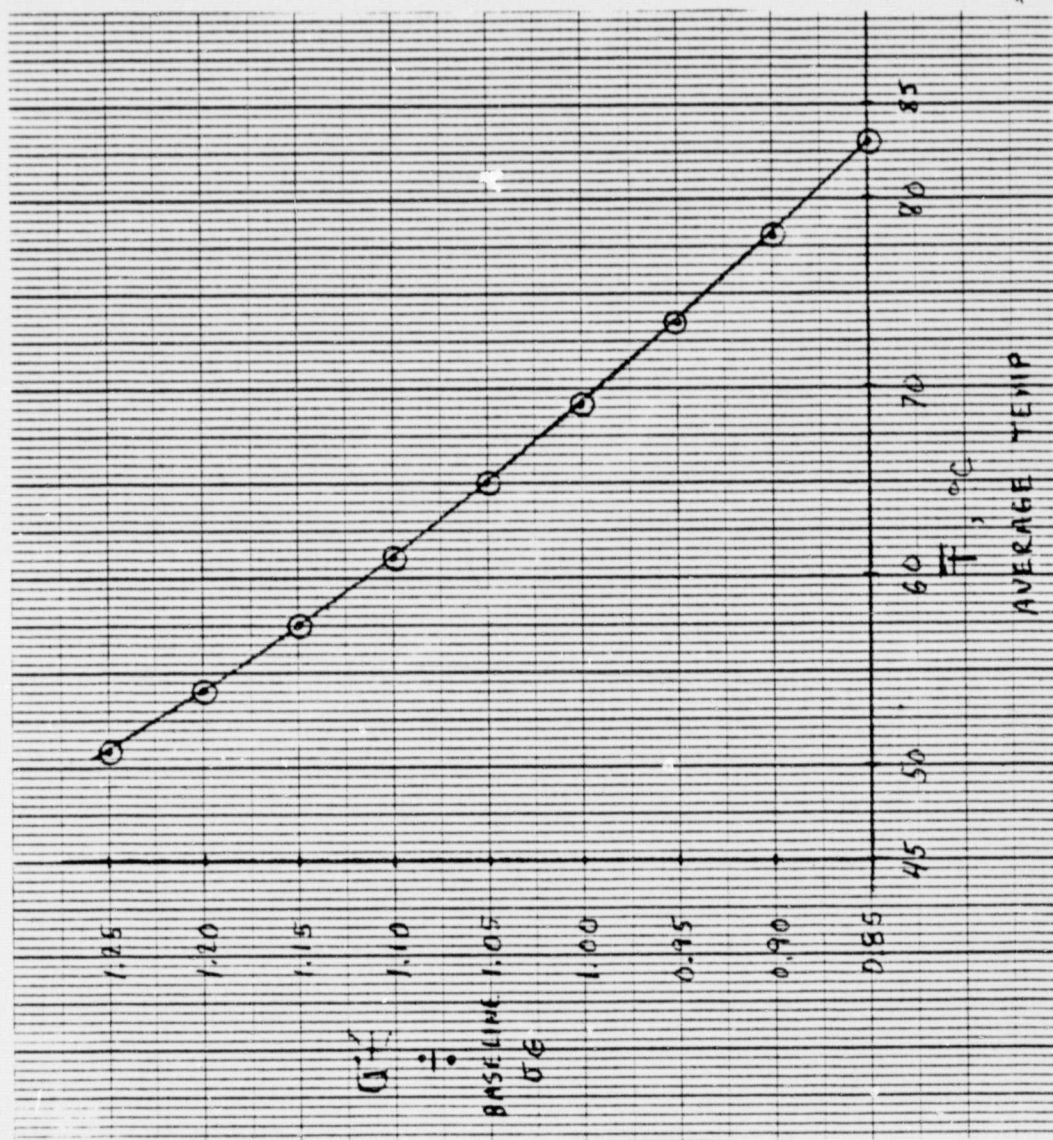
$$\sum_{i=1}^n \log \frac{f_i(x)}{g_i(x)} = \log \frac{f(x)}{g(x)}$$

46 1320

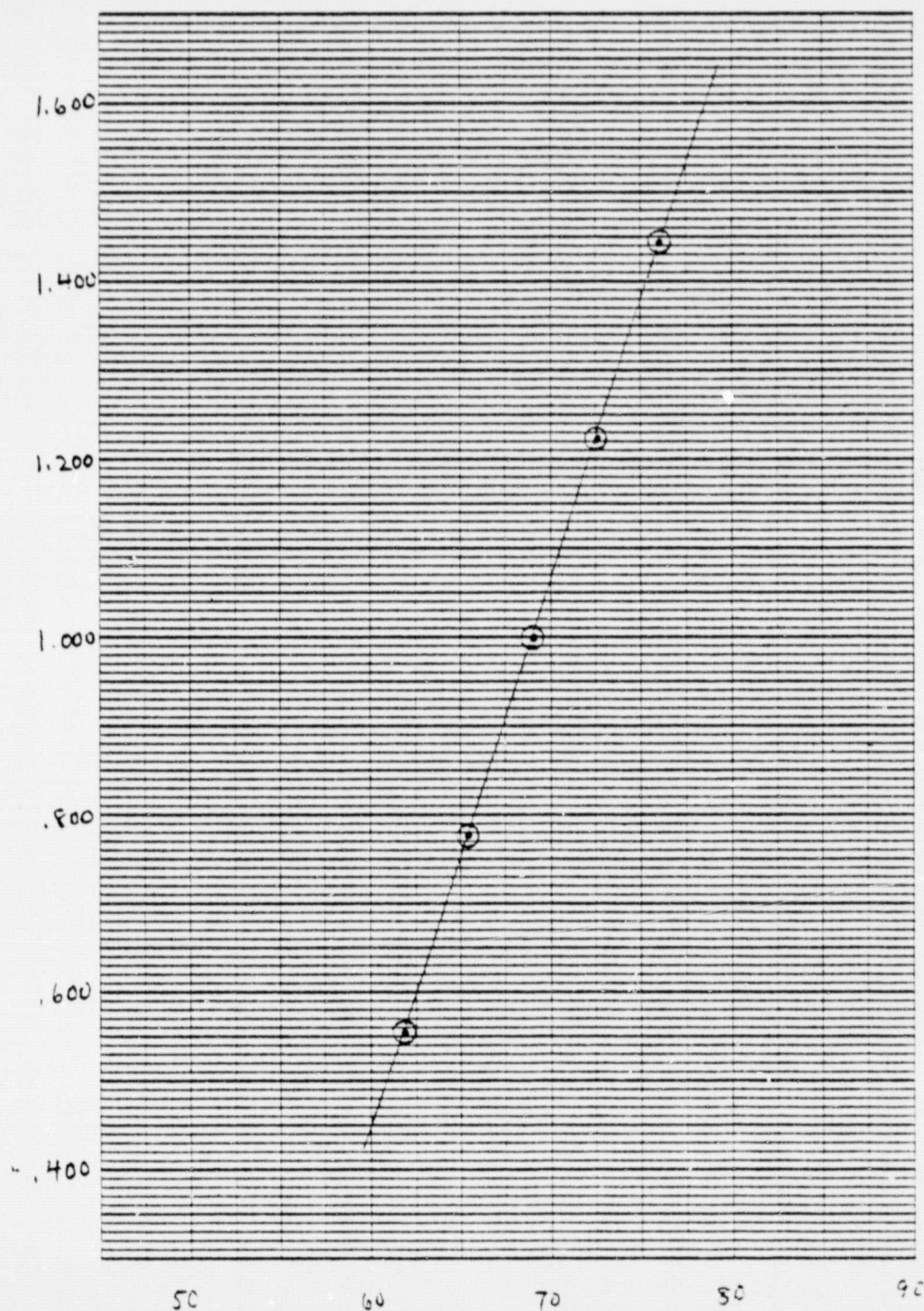
Exhibit 8a



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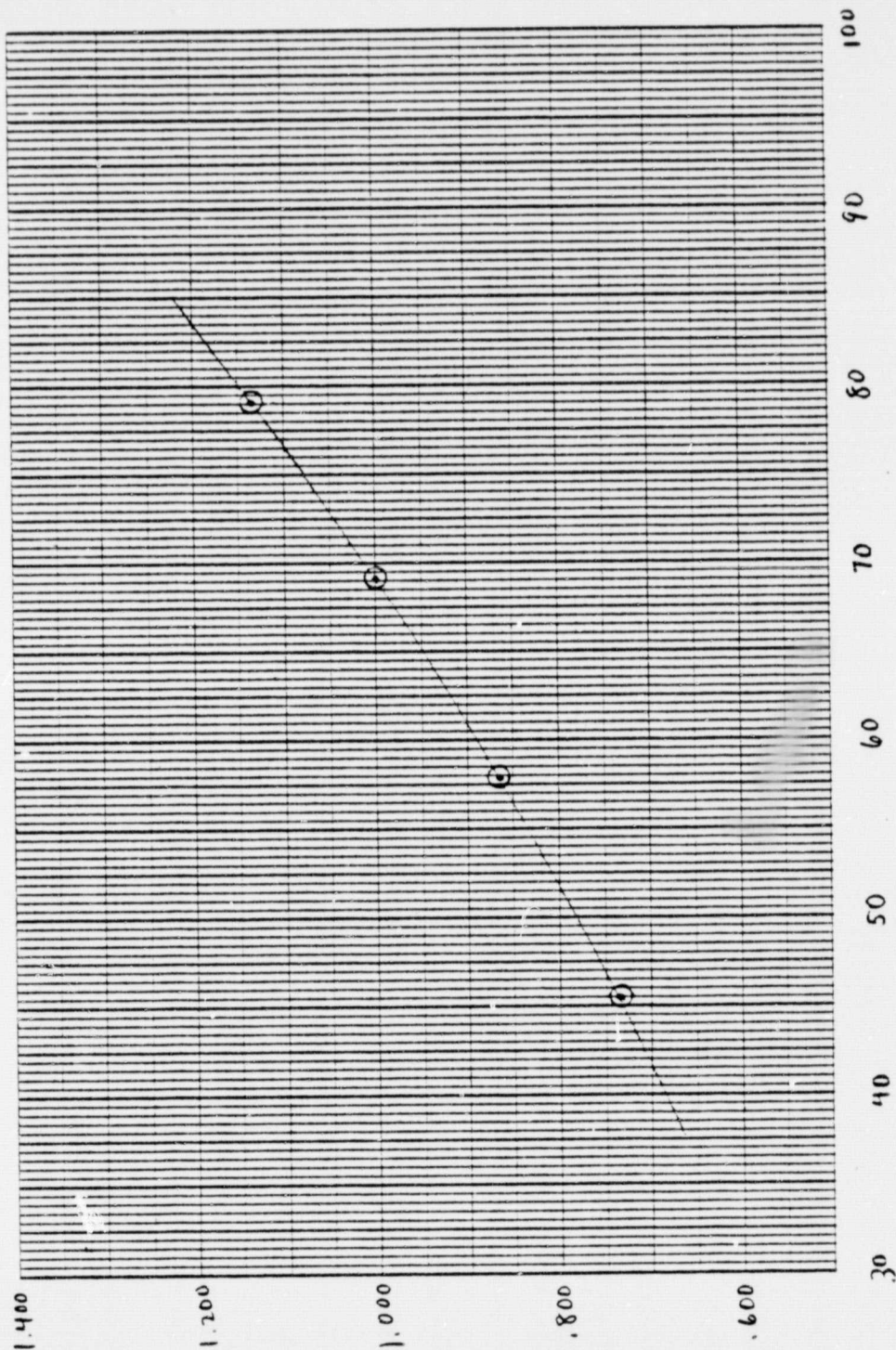


α_B
:
Baseline
 α_B



Average Temperature

°C



Average Temperature
°C

α_F

∴

Baseline

α_F

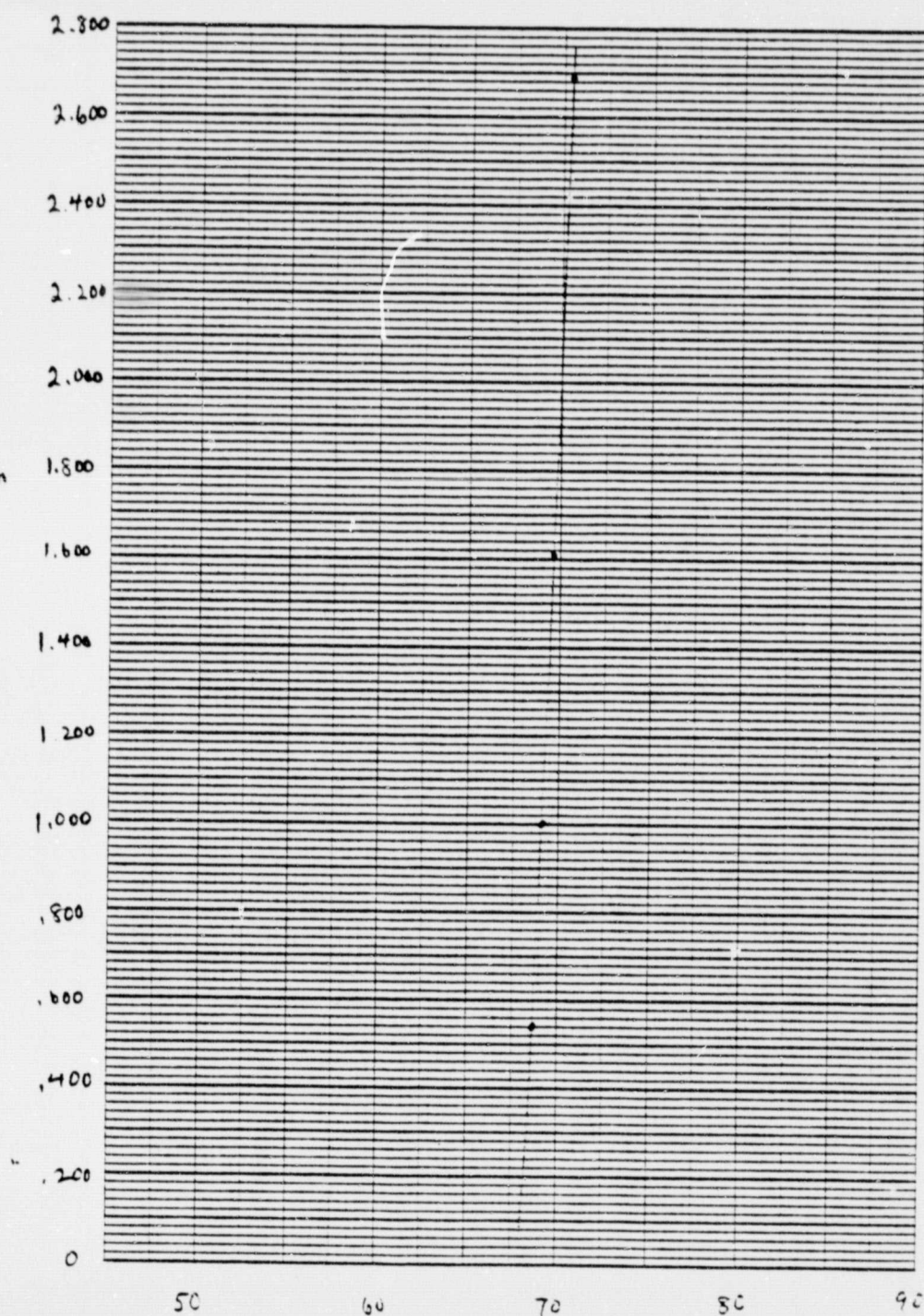
D-6

$g_{\text{space platform}}$

\div

Baseline

g_{sp}

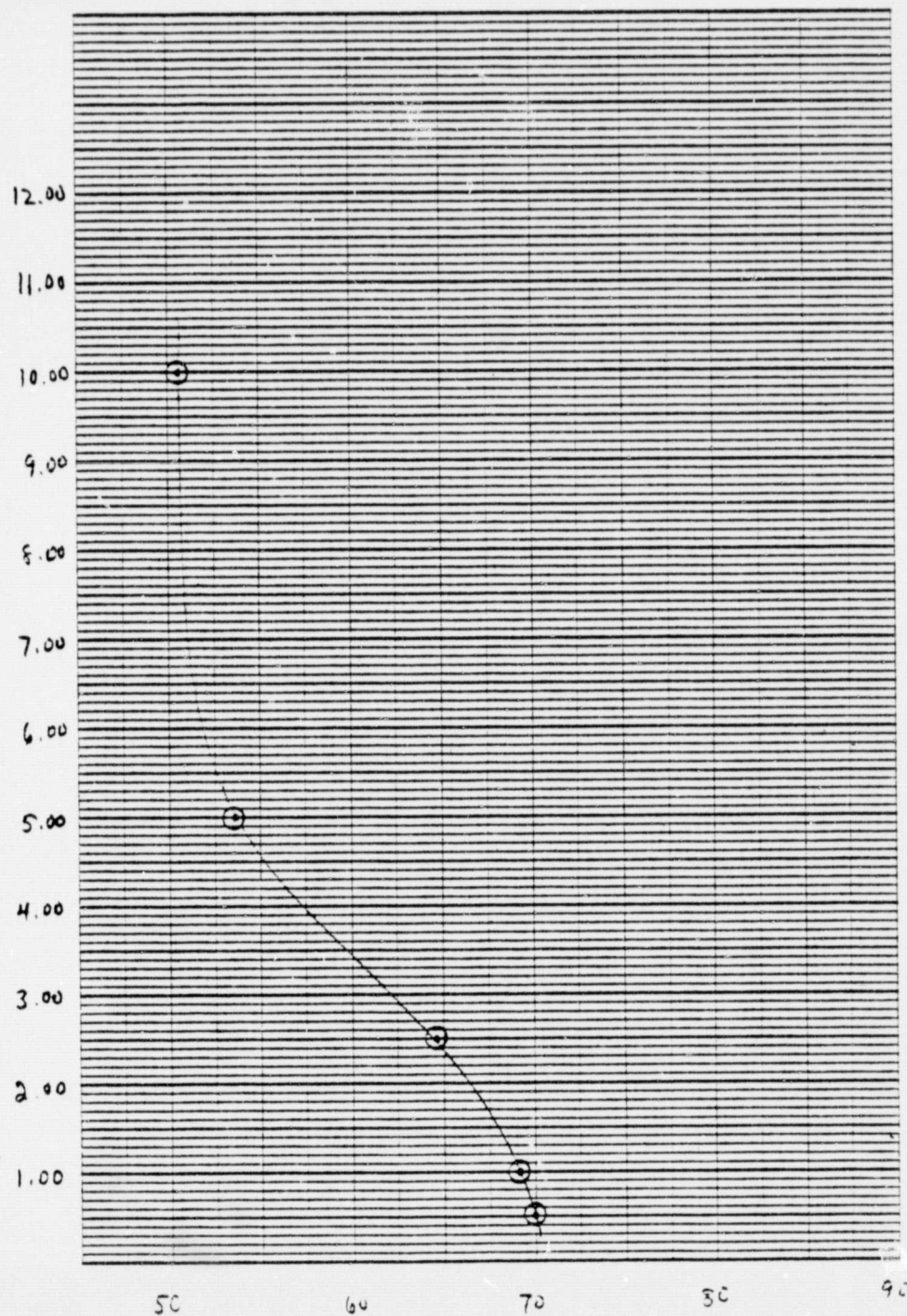


Average Temperature

°C

D-7

$\bar{m} \bar{c}_p$
+
Baseline
 $\bar{m} \bar{c}_p$



Average Temperature

°C

D-8

Packing Factor

\div

Baseline
Packing Factor

1.100

1.050

1.000

.950

.900

50

60

70

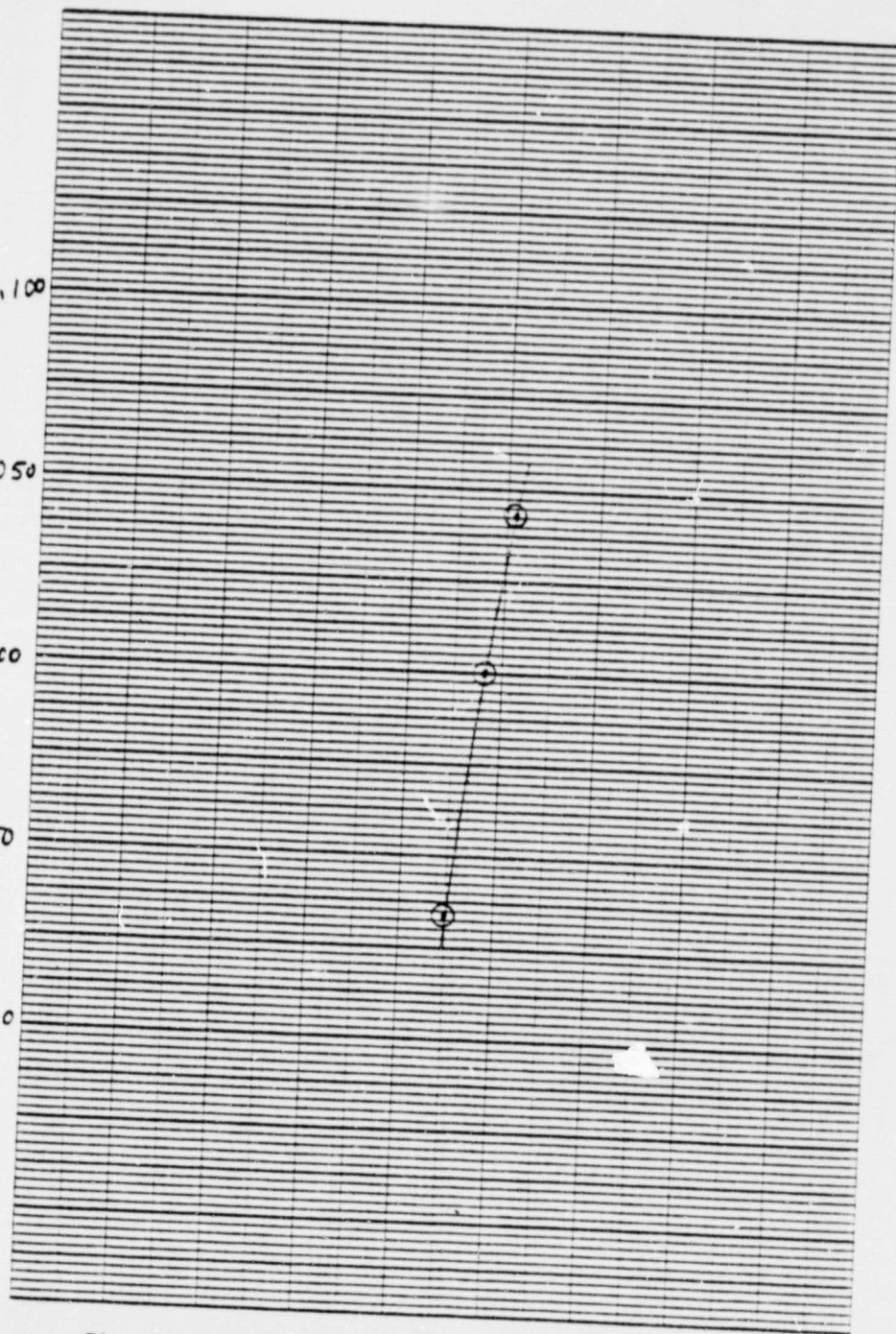
80

90

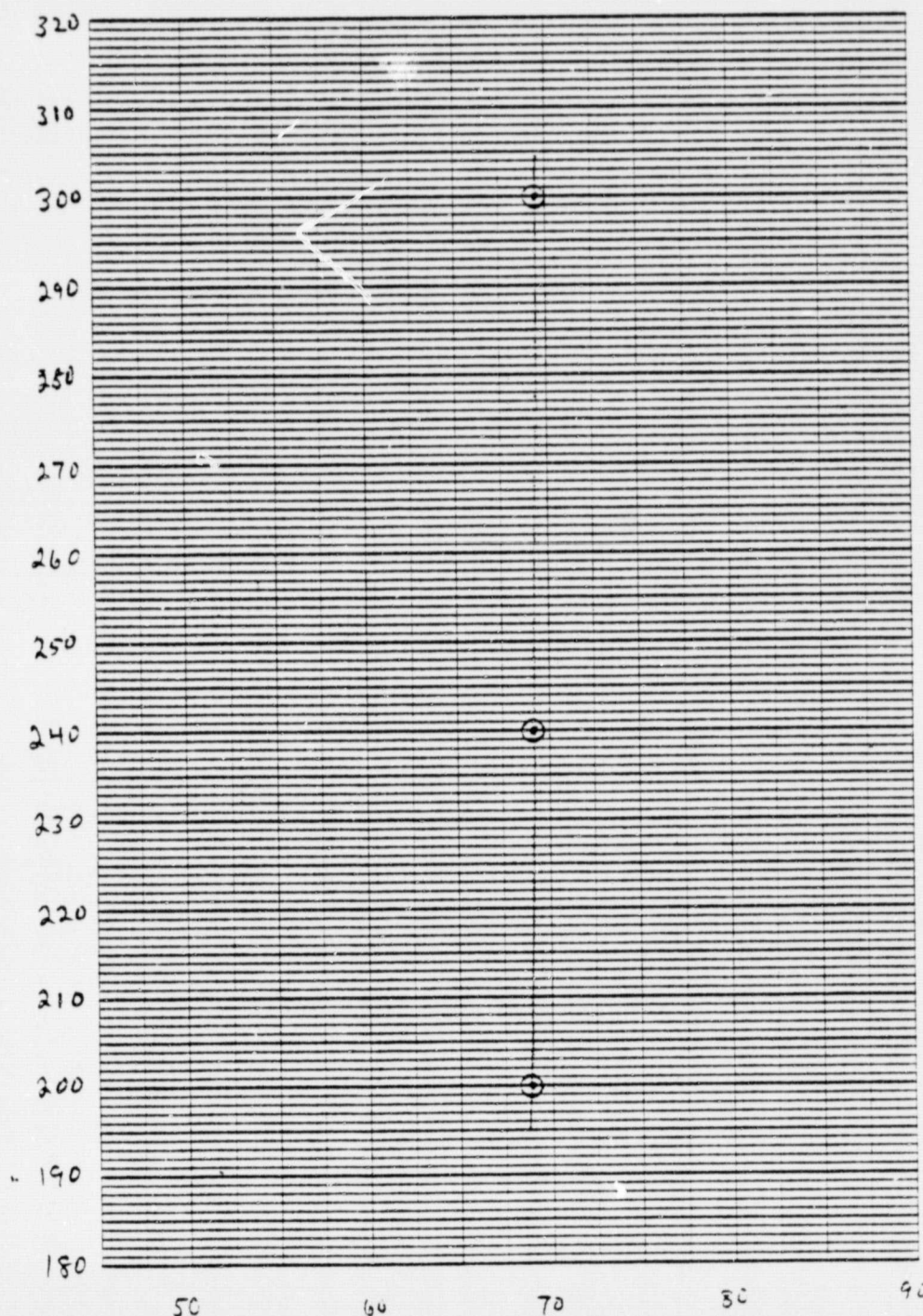
Average Temperature

°C

D-9



Orbit
Altitude,
Nm



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Average Temperature

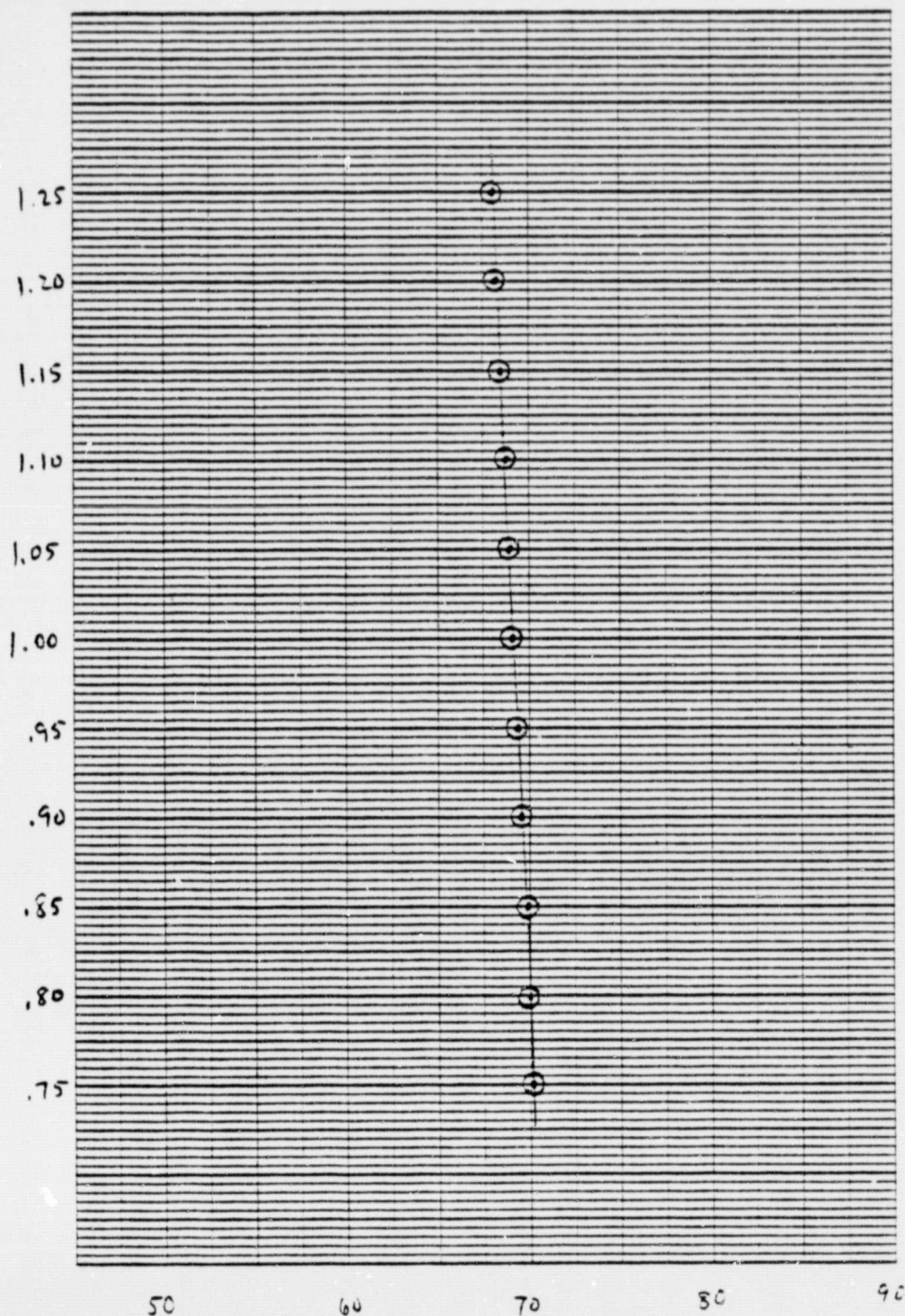
°C

D-10

g Electrical

Baseline

gE

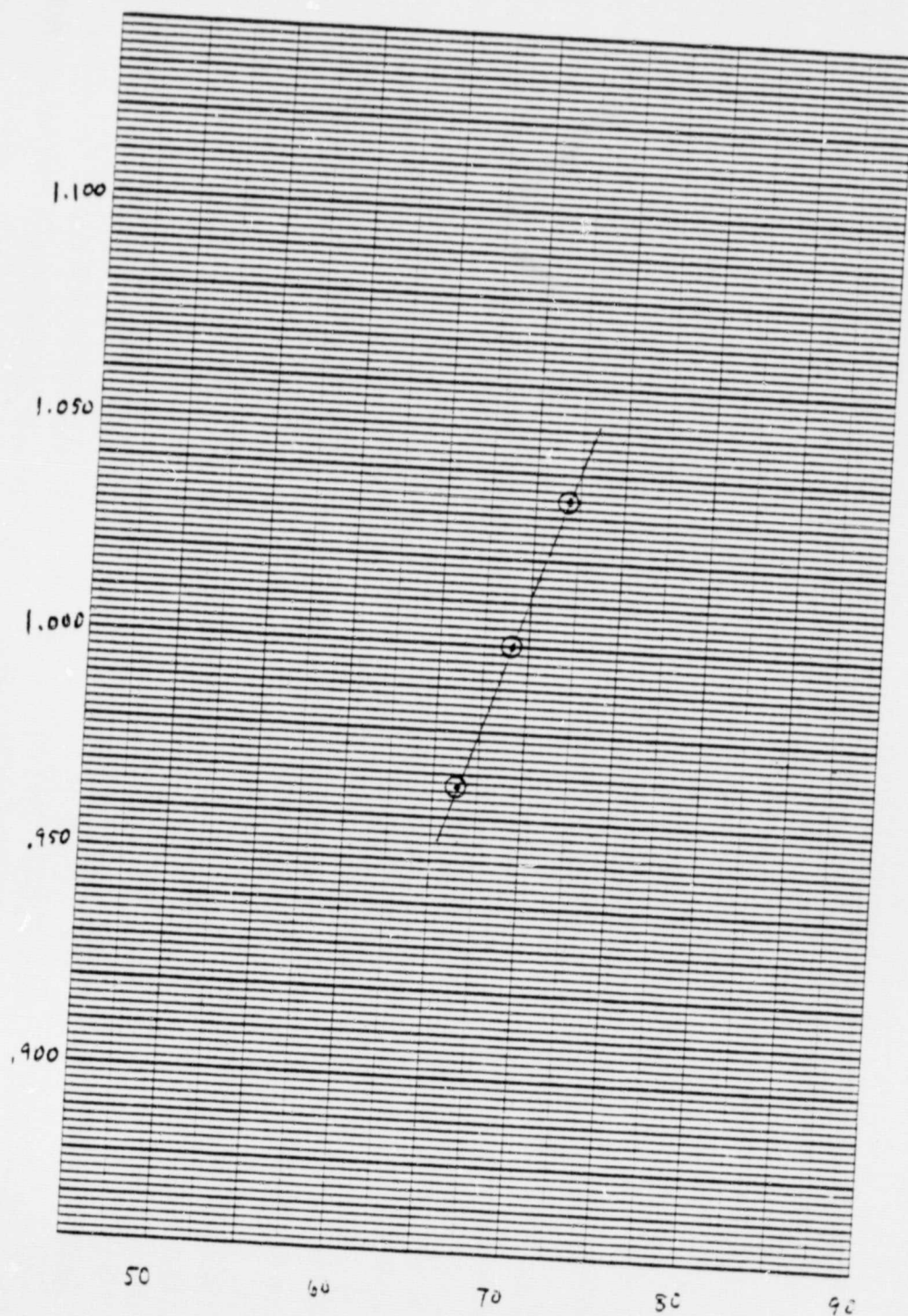


Average Temperature

°C

Illumination
(w/m^2)

\div
1353 w/m^2



Average Temperature

$^{\circ}\text{C}$

D-12

APPENDIX E

SACPM PROGRAM DATA PRINTOUT (TI-59)

Appendix E consists of a sample TI-59 SACPM program printout for the solar array baseline described in Section 2.0 of this report. The program used to generate the printout is described in Appendix C of this report. A plot of the temperature profile calculated by the temperature subroutine is shown on page D-3 in Appendix D.

PHYSICAL SUBROUTINE

4. 0.13 2.022 0.13 8.088 8.888 0.91	L L W W AC HS PF	0.1 2. 1030. 0.0549 8.088 0.0434	T D M A W	1. 8. 2600. 0.5283 8.088 0.4273	T D M A W	3.1 0.5 1400. 0.0178 8.888 0.0158	T D M A W
0. 6. 2200. 0.3853 8.088 0.2712	T D M A W	2. 1030. 0.98	T D T	8. 975. 2.55	T D T	0.5 1400. 0.32	T D T
6. 2200. 6.	T D T	0.05 660. 33. 725. 36. 795. 40. 865. 43. 910. 46. 945. 47. 985. 49. 1000. 50. 1015. 51.	M CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP	0.4808 500. 240. 560. 269. 615. 296. 650. 313. 700. 337. 720. 346. 725. 349. 735. 353. 750. 361.	M CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP	0.0178 725. 13. 800. 14. 875. 16. 950. 17. 1000. 18. 1040. 19. 1085. 19. 1100. 20. 1115. 20.	M CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP
0.3051 475. 145. 510. 156. 575. 175. 625. 191. 675. 206. 720. 220. 765. 233. 800. 244. 850. 259.	M CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP						

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PHYSICAL SUBROUTINE (CONTINUED)

3.2	3.3	3.4	3.5
0.5 1420. 0.018 8.888 0.016	T D M H W	0.5 1420. 0.018 8.888 0.016	T D M H W
0.5 1420. 0.32	T D T.	0.5 1420. 0.32	T D T.
0.018 725. 13. 800. 14. 875. 16. 950. 17. 1000. 18. 1040. 19. 1085. 20. 1100. 20. 1115. 20.	M CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP	0.018 725. 13. 800. 14. 875. 16. 950. 17. 1000. 18. 1040. 19. 1085. 20. 1100. 20. 1115. 20.	M CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP
0.018 725. 13. 800. 14. 875. 16. 950. 17. 1000. 18. 1040. 19. 1085. 20. 1100. 20. 1115. 20.	M CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP	0.018 725. 13. 800. 14. 875. 16. 950. 17. 1000. 18. 1040. 19. 1085. 20. 1100. 20. 1115. 20.	M CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP MCP CP

TEMPERATURE SUBROUTINE (MINIMUM ILLUMINATION)

0. 1780. 185.6	5.04 1309. 342.1	15. 1309. 340.7	25. 1309. 349.2
0.191 1780. 210.6	6. 1309. 332.2	16. 1309. 342.0	26. 1309. 349.4
0.418 1780. 235.6	7. 1309. 329.7	17. 1309. 343.2	26.85 1309. 349.5
0.687 1780. 260.6	8. 1309. 330.0	18. 1309. 344.3	27. 1309. 349.5
1. 1779. 283.9	9. 1309. 331.3	19. 1309. 345.3	28. 1309. 349.6
1.452 1777. 308.9	10. 1309. 332.9	20. 1309. 346.2	29. 1309. 349.5
2. 1772. 328.5	11. 1309. 334.5	21. 1309. 347.0	30. 1309. 349.3
3. 1751. 345.3	12. 1309. 336.2	22. 1309. 347.7	31. 1309. 349.0
4. 1671. 348.5	13. 1309. 337.8	23. 1309. 348.3	32. 1309. 348.6
5. 1329. 342.7	14. 1309. 335.3	24. 1309. 348.8	33. 1309. 348.1

CHIEF OF POLICE

TEMPERATURE SUBROUTINE (MINIMUM ILLUMINATION) (CONTINUED)			
34. 1309. 347.4	44. 1309. 335.7	53. 1780. 353.4	57. 232.2
35. 1309. 346.7	45. 1309. 334.1	53.7 1780. 354.2	58. 220.8
36. 1309. 345.8	46. 1309. 332.4	1383. 339.5	59. 213.4
37. 1309. 344.9	47. 1309. 330.6	53.7 354.2	60. 208.8
38. 1309. 343.9	48. 1309. 328.8	53.998 329.2	61. 206.1
39. 1309. 342.7	48.66 1309. 327.6	54. 329.0	62. 204.7
40. 1309. 341.5	49. 1476. 328.5	54.404 304.0	63. 204.3
41. 1309. 340.2	50. 1708. 339.5	54.973 279.0	64. 204.5
42. 1309. 338.8	51. 1760. 347.6	55. 278.0	65. 205.2
43. 1309. 337.3	52. 1775. 351.5	55.858 253.0	66. 206.1
		56. 249.8	67. 207.1
			68. 208.0
			69. 208.9

TEMPERATURE SUBROUTINE (MINIMUM ILLUMINATION) (CONTINUED)		TEMPERATURE SUBROUTINE (MAXIMUM ILLUMINATION)	
70. 209.6	82. 201.3	0. 1903. 185.6	5. 1421. 348.3
70.47 209.9	83. 198.9	0.178 1903. 210.6	5.04 1399. 347.6
71. 210.2	84. 196.3	0.388 1902. 235.6	6. 1399. 337.4
72. 210.6	85. 193.3	0.635 1902. 260.6	7. 1399. 335.0
73. 210.7	86. 190.1	0.943 1901. 285.6	8. 1399. 335.4
74. 210.7	87. 186.5	1. 1901. 289.6	9. 1399. 336.7
75. 210.4	87.24 185.6	1.432 1899. 314.6	10. 1399. 338.3
76. 209.9		2. 1894. 335.5	11. 1399. 340.0
77. 209.1		3. 1871. 351.9	12. 1399. 341.6
78. 208.1		4. 1786. 354.6	13. 1399. 343.2
79. 206.8			
80. 205.2			
81. 203.4			

TEMPERATURE SUBROUTINE (MAXIMUM ILLUMINATION) (CONTINUED)			
14. 1399. 344.7	24. 1399. 354.2	33. 1399. 353.4	43. 1399. 342.6
15. 1399. 346.1	25. 1399. 354.6	34. 1399. 352.8	44. 1399. 341.0
16. 1399. 347.4	26. 1399. 354.8	35. 1399. 352.0	45. 1399. 339.4
17. 1399. 348.6	26.85 1399. 354.9	36. 1399. 351.2	46. 1399. 337.7
18. 1399. 349.7	27. 1399. 354.9	37. 1399. 350.2	47. 1399. 335.9
19. 1399. 350.7	28. 1399. 355.0	38. 1399. 349.2	48. 1399. 334.1
20. 1399. 351.6	29. 1399. 354.9	39. 1399. 348.1	48.66 1399. 332.9
21. 1399. 352.4	30. 1399. 354.7	40. 1399. 346.8	49. 1577. 333.9
22. 1399. 353.1	31. 1399. 354.4	41. 1399. 345.5	50. 1826. 345.4
23. 1399. 353.7	32. 1399. 354.0	42. 1399. 344.1	51. 1881. 353.6

TEMPERATURE SUBROUTINE (MAXIMUM ILLUMINATION) (CONTINUED)

52. 1897. 357.4	56. 251.3	69. 208.9	81. 203.4
53. 1902. 359.2	57. 233.2	70. 209.6	82. 201.3
53.7 1903. 360.0	58. 221.5	70.47 209.9	83. 198.9
1478. 344.9	59. 213.9	71. 210.2	84. 196.3
53.7 360.0	60. 209.1	72. 210.6	85. 193.3
53.979 335.0	61. 206.3	73. 210.7	86. 190.1
54. 333.4	62. 204.9	74. 210.7	87. 186.5
54.383 308.4	63. 204.5	75. 210.4	87.24 185.6
54.918 283.4	64. 204.7	76. 209.9	
55. 280.3	65. 205.3	77. 209.1	
	66. 206.1	78. 208.1	
	67. 207.1	79. 206.8	
55.827 255.3	68. 208.0	80. 205.2	

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MAIN BUS SUBROUTINE	
4130.02152	08
50.01	09
854.0960	10
1305.000743	11
0.	12
0.	13
0.	14
0.	15
0.122	16
0.	17
0.479	18
0.	19
.00000000824	20
0.	21
0.	22
0.000888	23
0.0008734	24
5753.	25
169116.	26
0.000000026	27
24.	28
600.	29

SOLAR CELL SUBROUTINE P (EOL)
mp

0.738 0.965 0.993 0.999 0.999 0.999 0.955 0.988 1.000 0.800 0.854 0.455	0.054 1383. 1.017 0.870 1224. 339.5 340.2	0.787 1.000 0.993 0.999 0.999 0.999 0.955 0.988 1.000 1.000 0.968 0.712	0.717 0.965 0.993 0.999 0.999 0.999 0.961 0.988 1.000 0.968 0.716
0.056 1383. 1.017 0.870 1224. 339.5 340.0	0.054 1383. 1.017 0.870 1224. 339.5 340.2	0.053 0.341	0.787 1.000 0.993 0.999 0.999 0.999 0.961 0.988 1.000 0.968 0.716
0.718 0.965 0.993 0.999 0.999 0.999 0.955 0.988 1.000 0.800 0.854 0.442	0.054 1383. 1.017 0.870 1224. 339.5 340.2	0.054 1383. 1.017 0.870 1224. 339.5 340.2	0.053 0.341 0.053 0.343

SOLAR CELL SUBROUTINE V _{mp} (EOL)		
0.717 0.965 0.993 0.999 0.999 0.999 0.961 0.988 1.000 0.800 0.854 0.444 0.054 1478. 1.017 0.870 1308. 344.9 345.6 0.738 0.965 0.993 0.999 0.999 0.961 0.988 1.000 0.800 0.854 0.457	0.056 1478. 1.017 0.870 1308. 344.9 345.4 0.739 0.965 0.993 0.999 0.999 0.961 0.988 1.000 0.800 0.854 0.458 0.056 1478. 1.017 0.870 1308. 344.9 345.4 0.739 0.965 0.993 0.999 0.999 0.961 0.988 1.000 0.800 0.854 0.456	0.739 0.965 0.993 0.999 0.999 0.961 0.988 1.000 0.800 0.854 0.456 0.759 1.000 0.993 0.999 0.999 0.957 0.988 1.000 1.000 0.968 0.688 0.059 0.331 0.739 0.965 0.993 0.999 0.999 0.957 0.988 1.000 0.800 0.854 0.456 0.056 1478. 1.017 0.870 1308. 344.9 345.4 0.739 0.965 0.993 0.999 0.999 0.961 0.988 1.000 0.800 0.854 0.458

ORIGINAL PAGE 1
OF 100

LCCM SUBROUTINE			
9072000. 9648. 2880. 192. 8434. 11940. 43.23	53 54 55 56 57 58 59	1.466 2.774 0.418 3.703 4.305 0.027 0.06 12.753	12.753 34.051 99.274 9.927 141.535 9.907 0.945 0.06 261.648 295.699 376.1 63.029 0.779 63.803 439.903 153.968 0.408 0.783 0.9 2.5 146.25 11. 153.75 160.65 754.526
7.75 0.3665 .0000003058 .0000433167 .0012857639 0.022421875 .00000031583 .00000049925 0.07775 .0000100747 .0001848798 .0002572917 .0102604167. .0003639953 .0000156013 0.945 .0000028278 .0027517805 4.228 .0000274403 0.18 23. 0.408 2.5 146.25 11:	04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29	0.311 91.398 1.784 0.741 1.97 3.07 99.274	35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59